NASA CR- 66250

REPORT NO. 41-65

CONTROL NO.U-65-41B

NASA

FACILITY FORM 602

N67 13570 (ACCESSION NUMBER)	(THRU)
204 (PAGES)	1 (CODE)
CR-66250 (NASA CR OR TMX OR AD NUMBER)	28 (CATEGORY)

GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) 6.00

Microfiche (MF) 1.25

ff 653 July 65

DESIGN AND DEVELOPMENT OF THE CASTOR IIA ROCKET MOTOR

U

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT DA-01-021-506-ORD-1269 (Z)
MODIFICATIONS 25,28,34,AND 36 THROUGH 42
NASA ORDER NO.L-15,993

Thiokol
CHEMICAL CORPORATION
HUNTSVILLE DIVISION
HUNTSVILLE, ALABAMA

Report No. 41-65
Control No. U-65-41 B

Thiokol
CHEMICAL CORPORATION
HUNTSVILLE DIVISION
HUNTSVILLE, ALABAMA

FINAL REPORT

DESIGN AND DEVELOPMENT OF THE CASTOR IIA ROCKET MOTOR

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract DA-01-021-506-ORD-1269(Z)
Modifications 25, 28, 34, and 36 through 42
NASA Order No. L-15,993

Prepared by:

W W Barnes
W. W. Barnes
Assistant Project Manager

Approved by:

G F Mangum
G. F. Mangum
Project Manager

B. D. Herbert
Director
Project Management

Published
4 February 1966

BLANK PAGE

CONTENTS

Page No.

1 INTRODUCTION
1 SUMMARY
2 CONTRACT OBJECTIVES
2 CONTRACT DESCRIPTION
4 CONTROLLING DOCUMENTATION
4 SUMMARY OF DOCUMENTATION AND REPORTS
4 MOTOR DESIGN
4 Design Summary
5 Technical Requirements
5 Motor Case Design
5 Nozzle Design
6 Case Insulation Design
7 Ignition System Design
8 Propellant Configuration Design
9 TOOLING DESIGN AND FABRICATION
10 PROPELLANT TAILORING
10 Propellant Summary
11 TP-H7019 and TP-H7021 Development
17 TP-H7025 Development
19 MOTOR CASE INSULATION DEVELOPMENT
19 Material Selection
20 Initial Application Method
20 Motor 12 Insulation Failure Evaluation
26 Results of Insulation Failure Evaluation
27 Insulation Corrective Action
28 MOTOR CASE LINER DEVELOPMENT
29 IGNITION SYSTEM DEVELOPMENT
29 Ignition System Summary
30 Ignition System Design
30 Pyrogen Case Tests
31 Pellet Assembly Tests
31 Ignition System Tests

CONTENTS (Cont'd)

Page No.	
32	MOTOR CASE HYDROBURST TEST
35	MOTOR LOADING
35	Loading Summary
35	Loading Procedure
36	Propellant Mix Characteristics
36	Motor 2 Anomalies
37	Propellant Blemishes in Motor 3
37	Separation in Motors 3 and 9
38	MOTOR DEVELOPMENT
38	Motor Development Summary
38	Development Test 1, Motor 1
39	Development Test 2, Motor 3
40	Development Test 3, Motor 4
41	ATHENA Motor 8
42	ATHENA Motor 9
43	ATHENA Motor 11
43	ATHENA Motor 12
44	MOTOR PFRT
44	PFRT Summary
45	PFRT Propellant Ballistics
45	PFRT Propellant Physicals
46	PFRT Ballistic Performance Evaluation
46	PFRT Ignition Evaluation
49	PFRT Unburned Propellant
49	PFRT Inert Parts Evaluation
49	NOZZLE CLOSURE DEVELOPMENT
51	NOZZLE EXTERNAL INSULATION DEVELOPMENT
51	External Insulation Summary
51	Thermocouple Data
52	Temperature Prediction for Exterior of Cork
53	SHIPPING CONTAINER MODIFICATION
55	CONCLUSIONS
56	RECOMMENDATIONS

CONTENTS (Cont'd)

TABLES

FIGURES

APPENDIX A. List of Reports Submitted Under the Contract.

APPENDIX B. Master Parts List AR-42300.

APPENDIX C. Applicable Thiokol Specifications and Process Standards.

APPENDIX D. Listing of Test and Inspection Procedures.

APPENDIX E. Load Conditions of the TX354-3 Case and Nozzle.

APPENDIX F. Tooling Parts List.

TABLES

Table I. Tabulation of TX354-3 PFRT Motor Performance versus Requirements of NASA Development Specification P39-023.

Table II. Motor Case Flexural Stiffness.

Table III. Nozzle Flexural Stiffness.

Table IV. PYROGEN Propellant Characteristics.

Table V. Characteristics of Boron Potassium Nitrate Pellets.

Table VI. Electric Initiator Characteristics (CR-38682).

Table VII. TP-H7019 and TP-H7021 Propellant Tailoring Mix History.

Table VIII. Tear Resistance versus Temperature of TP-H7019 Having Various Stoichiometric Ratios.

Table IX. Effect of Temperature and Stoichiometry on the Bond Strength of TP-H7019 Propellant to TL-H711B Liner.

Table X. Properties of Mix B-1931 - TP-H7021 Propellant.

Table XI. Formulations of Propellants Screened for the TX-354 Motor.

Table XII. Physical Properties and Burning Rates of Propellants Screened for the TX-354 Motor.

Table XIII. Properties of Standardization Mixes of TP-H7025 Propellant.

Table XIV. Insulation Erosion in TX-24 (Test 1).

Table XV. Insulation Erosion in TX-24 (Test 2).

Table XVI. Insulation Erosion in TX-24 (Test 3).

Table XVII. Adhesive Strength of TI-O700A Insulation to Grit Blasted Steel.

Table XVIII. Adhesive Strength of TL-H711B Liner to TI-O700A Insulation at Three Temperatures Through Twelve Weeks Storage Time.

Table XIX. Peel Strength of TL-H711B Liner to TI-O700A and Grit Blasted Steel at Three Temperatures Through Twelve Weeks Storage Time.

Table XX. Tensile Strength of TL-H711B Liner and TI-O700A Insulation.

Table XXI. Lot Numbers of Raw Materials used for Insulation of TX-354 Motors.

Table XXII. Ultimate Stress and Elongation of TI-O700A as Functions of Loading Rates.

Table XXIII. Raw Materials, Percent by Weight, for TI-O700A Insulation Used in TX-354 Motors.

Table XXIV. Dates Insulation Mixes Weighed, Mixed, Placed in Cure.

Table XXV. Retained Insulation Weights for TX-354 Motors.

Table XXVI. Peel Strength of TL-H711B Liner to TP-H7021 Propellant at Three Temperatures Through Twelve Weeks Storage Time.

TABLES (Cont'd)

Table XXVII. Data From Hydrotest of TX-362 PYROGEN Cases.
Table XXVIII. Summary of PYROGEN Units Loaded.
Table XXXIX. PYROGEN Unit Tests.
Table XXX. Physical Properties of Tensile Specimens Machined from Hydroburst Case.
Table XXXI. Summary of TX354 Motors Loaded and Disposition.
Table XXII. Propellant Mix Summary.
Table XXXIII. Static Pressure Test Summary.
Table XXXIV. Dynamic Test Summary - Closure R 42653.

FIGURES

Figure 1. TX354 Motor Assembly.

Figure 2. TX354 Loaded Case Configuration.

Figure 3. Station Locations for Motor Case Flexural Stiffness Determinations.

Figure 4. TX354 Nozzle Assembly.

Figure 5. Station Locations for Nozzle Flexural Stiffness Determinations.

Figure 6. Erosion Profile of Motor Case Insulation from TX354 Motor 5.

Figure 6A. Erosion Profile of Nozzle Assembly Used on TX354 Motor 5.

Figure 7. Erosion Profile of Motor Case Insulation from TX354 Motor 22.

Figure 7A. Erosion Profile of Nozzle Assembly Used on TX354 Motor 22.

Figure 8. TX362 Pyrogen Ignition System.

Figure 9. Typical Pyrogen Igniter Versus Time Curve.

Figure 10. Electric Initiator (CR-38682).

Figure 11. Pyrogen Nozzle Section, TX354 Motor 6.

Figure 12. Original Propellant Configuration of the TX354 Castor IIA Design.

Figure 13. Typical Trace of Pressure and Thrust Versus Time at 77°F Vacuum for TX354 Motor.

Figure 14. Variation in Chamber Pressures During Ignition Period for TX354 Motors 1, 3, 8 and 9.

Figure 15. Variation in Thrust with Chamber Pressure for TX354 Motors 1, 3, 8, and 9.

Figure 16. Comparison of Pressures Recorded at Three Stations in TX354 Motor 9.

Figure 17. Variation in Measured Strains with Time at Three Stations on the Case of TX354 Motor 9.

Figure 18. Comparisons of Head-End Pressure and Thrust for Theoretical and Actual Motor Performance in TX354 Motor 9.

Figure 19. Schematic Diagram of Water Table Setup.

Figure 20. Effect of Downstream Static Pressure on the Pressure Ratio Across the Head-End Slot.

Figure 21. Effect of Downstream Static Pressure on the Pressure Ratio Across the Aft-End Slot.

Figure 22. Pressure Distribution Along the Wall of the Aft-End Slot with a Propellant Radium of 1-Inch.

Figure 23. Pressure Distribution Along the Wall of the Aft-End Slot with a Propellant Radius of 5 Inches.

Figure 24. Pressure Distribution Along the Wall of the Forward Slot with a Propellant Radius of 1-Inch.

Figure 25. Pressure Distribution Along the Wall of the Forward Slot with a Propellant Radius of 5 Inches.

FIGURES (Cont'd)

Figure 26. Packing Study Results of NH_4ClO_4 and Aluminum Powder Blends Used in DTS-4884 Propellant.

Figure 27. Packing Study Results of NH_4ClO_4 and Aluminum Powder Blends Used in DTS-4884 Propellant.

Figure 28. Packing Study Results of NH_4ClO_4 and Aluminum Powder Blends Used in TP-H7019 Propellant.

Figure 29. Static Tested TX-3 Motors Using TP-H7019 Propellant, Mix No. J-2619, Over a Wide Temperature Range.

Figure 30. Results of TP-H7019 Propellant Physically Tested Over a Wide Temperature Range.

Figure 31. Static Tested TX-3 Motor Using TP-H7019 Propellant, Mix F-947, Over a Wide Temperature Range.

Figure 32. Static Tested TX-3 Motors Using TP-H7019 Propellant, Mix F-950, Over a Wide Temperature Range.

Figure 33. Shear Rate versus Shear Stress of Mix F-905.

Figure 34. Shear Rate versus Shear Stress of Mix F-906.

Figure 35. Shear Rate versus Shear Stress of Mix F-909.

Figure 36. Shear Rate versus Shear Stress of Mix F-910.

Figure 37. Severs Viscosity versus Shear Rate of Mix F-905.

Figure 38. Severs Viscosity versus Shear Rate of Mix F-906.

Figure 39. Severs Viscosity versus Shear Rate of Mix F-909.

Figure 40. Severs Viscosity versus Shear Rate of Mix F-910.

Figure 41. Viscosity versus Time for TP-H7019 Propellant (1/.85 Stoichiometric Ratio).

Figure 42. Viscosity versus Time for TP-H7019 Propellant (1/.825 Stoichiometric Ratio).

Figure 43. Viscosity versus Time for TP-H7019 Propellant (1/.80 Stoichiometric Ratio).

Figure 44. Viscosity versus Time for TP-H7019 Propellant (1/.775 Stoichiometric Ratio).

Figure 45. Tensile Properties of TP-H7019 Propellant from Mix F-905.

Figure 46. Tensile Properties of TP-H7019 Propellant from Mix F-906.

Figure 47. Tensile Properties of TP-H7019 Propellant from Mix F-909.

Figure 48. Tensile Properties of TP-H7019 Propellant from Mix F-910.

Figure 49. Tensile Properties of TP-H7019 Propellant from Mix F-935.

Figure 50. Tensile Properties of TP-H7019 Propellant from Mix F-936.

Figure 51. Variation of Induced Propellant Strain with Storage Temperature in the TX354.

FIGURES (Cont'd)

Figure 52. Variation of Maximum Tangential Strain with Temperature.

Figure 53. Tensile Properties of TP-H7021 Propellant from Mix F-979.

Figure 54. Tensile Properties of TP-H7021 Propellant from Mix F-982.

Figure 55. Variation of Maximum Tangential Strain with Temperature and Cycling for Mix F-979 Containing TP-H7021 Propellant.

Figure 56. Variation of Maximum Tangential Strain with Temperature and Cycling for Mix F-982 Containing TP-H7021 Propellant.

Figure 57. Variation of Maximum Tangential Strain with Temperature and Cycling for Mix B Containing TP-H7021 Propellant.

Figure 58. Variation of Maximum Tangential Strain with Temperature and Cycling for Mix F-979 Containing TP-H7021 Propellant.

Figure 59. Variation of Maximum Tangential Strain with Temperature and Cycling for Mix F-982 Containing TP-H7021 Propellant.

Figure 60. Variation of Maximum Tangential Strain with Temperature and Cycling for Mix F-929 Containing TP-H7019 Propellant.

Figure 61. Effect of High Temperature Storage on the Physical Properties of TP-H7021 Propellant from Mix F-930.

Figure 62. Effect of High Temperature Storage on the Physical Properties of TP-H7019 Propellant from Mix F-929.

Figure 63. Effect of High Temperature Storage on the Physical Properties of TP-H7021 Propellant from Mix F-930.

Figure 64. Effect of High Temperature Storage on the Physical Properties of TP-H7019 Propellant from Mix F-929.

Figure 65. Effect of High Temperature Storage on the Physical Properties of TP-H7021 Propellant from Mix F-930.

Figure 66. TX-24 Motor Cross Section.

Figure 67. Ultimate Stress (psi) of TI-O700A Insulation versus Rate of Loading at Ambient Temperature.

Figure 68. Projected Ultimate Stress (psi) of TI-O700A at Very High Loading Rates.

Figure 69. Percent Elongation of TI-O700A versus Rate of Loading at Ambient Temperature.

Figure 70. Projected Ultimate Strain of TI-O700A at Very High Loading Rates.

Figure 71. Pressure-Time History of Hydroburst of TX354 Motor Case S/N 433.

Figure 72. TX354 Motor Case S/N 433 After Burst.

Figure 73. Closeup of TX354 Motor Case S/N 433 After Burst.

Figure 74. Closeup of Area Where Failure Originated on TX354 Motor Case S/N 433.

Figure 75. Strain versus Pressure TX354 Motor Case S/N 433.

Figure 76. Typical Casting Sequence for Dual Loading of TX354 Motors.

FIGURES (Cont'd)

Figure 77. Photograph Showing Typical Left Side of TX354 Motor Before Test.

Figure 78. Photograph Showing Typical Right Side of TX354 Motor After Test.

Figure 79. Another View of Typical TX354 Motor Before Test.

Figure 80. Typical TX354 Motor After Test.

Figure 81. Data Summary of TX354 Motor 1 from Mixes B-2007, B-2008, and B-2014.

Figure 82. Pressure and Thrust versus Time of TX354 Motor 1.

Figure 83. Head-End and Pyrogen Igniter Pressure versus Time of TX354 Motor 1.

Figure 84. Data Summary of TX354 Motor 3 from Mixes B-2083, B-2084 and B-2085.

Figure 85. Pressure and Thrust versus Time of TX354 Motor 3.

Figure 86. Motor Chamber and Pyrogen Igniter Pressure versus Time of TX354 Motor 3.

Figure 87. Data Summary of TX354 Motor 4.

Figure 88. Pressure versus Time of TX354 Motor 4.

Figure 89. Motor Chamber and Pyrogen Igniter Pressure versus Time of TX354 Motor 4.

Figure 90. Data Summary of TX-354 Motor 8 from Mixes B-2107 through B-2109.

Figure 91. Pressure and Thrust versus Time of TX354 Motor 8.

Figure 92. High Frequency Motor and Pyrogen Igniter Pressure versus Time of TX354 Motor 8.

Figure 93. Pressure and Thrust versus Time of TX354 Motor 9.

Figure 94. Data Summary of TX354-2 Motor 11 from Mixes B-2195 and B-2197.

Figure 95. Pressure and Thrust versus Time of TX354 Motor 11.

Figure 96. High Frequency Motor and Pyrogen Unit Pressure versus Time of TX354-2 Motor 11.

Figure 97. Data Summary of TX354 Motor 12 from Mixes B-2193, B-2195, B-2196 and B-2197.

Figure 98. Pressure and Thrust versus Time of TX354 Motor 12.

Figure 99. High Frequency and Pyrogen Igniter Pressure versus Time for TX354 Motor 12.

Figure 100. Aft-End of Nozzle After Test Showing Delaminations.

Figure 101. Pyrogen Ignition Case After Test of TX354 Motor 1.

Figure 102. Erosion Profile of Nozzle Used on TX354 Motor 3 During Static Test.

FIGURES (Cont'd)

Figure 103. Erosion Profile of Nozzle Used on TX354 Motor 4 During Static Test.

Figure 104. Erosion Profile of Nozzle Used on TX354 Motor 8 During Static Test.

Figure 105. Comparison of Theoretical Head-End Pressure and Thrust With Results Obtained for TX354 Motors 11 and 12.

Figure 106. Comparison of Ignition Phase Chamber Pressure versus Time for TX354 Motors 1, 3, 8, 9, 11, and 12.

Figure 107. Data Summary of TX354 Motor 5 from Mixes B-2230, B-2232, and B-2303.

Figure 108. Pressure and Thrust versus Time of TX354 Motor 5.

Figure 109. High Frequency Motor and Pyrogen Igniter Pressure versus Time of TX354 Motor 5.

Figure 110. Data Summary of TX354 Motor 6 from Mixes B-2287, B-2288, B-2293 and B-2295.

Figure 111. Pressure and Thrust versus Time of TX354 Motor 6.

Figure 112. High Frequency Motor and Pyrogen Igniter Pressure versus Time of Motor 6.

Figure 113. Data Summary of TX354 Motor 7 from Mixes B-2293, B- 2294, B-2295 and B-2287.

Figure 114. Pressure and Thrust versus Time of TX354 Motor 7.

Figure 115. High Frequency Motor and Pyrogen Igniter Pressure versus Time of TX354 Motor 7.

Figure 116. Data Summary of TX354 Motor 22 from Mixes B-2230, B-2232, B-2302 and B-2303.

Figure 117. Pressure and Thrust versus Time of TX354 Motor 22.

Figure 118. High Frequency Motor and Pyrogen Igniter Pressure versus Time of TX354 Motor 22.

Figure 119. Nozzle Closure Design of the TX354 Motor.

Figure 120. Closure Design Test 1.

Figure 121. Closure Design Test 2.

Figure 122. Closure Design Tests 3 through 6.

Figure 123. Closure Design Test 7.

Figure 124. Closure Design Tests 8 through 12.

Figure 125. External Insulation Developed for the Castor IIA Motor.

Figure 126. Steel Nozzle Exterior Temperature Data for Various TX354 Motor Tests.

Figure 127. Predicted Temperature for Exterior of Cork Blanket at Hottest Location.

Figure 128. Temperature Data From Sea Level Test of TX354 Motor 7.

Figure 129. Temperature Data From Sea Level Test of TX354 Motor 7.

FINAL REPORT

DESIGN AND DEVELOPMENT OF THE CASTOR IIA ROCKET MOTOR

CONTRACT DA-01-021-506-ORD-1269(Z), Mods. 25, 28, 34, and 36 through 42
NASA ORDER NO. L-15,993

INTRODUCTION

This final report discusses development of the Castor IIA (TX354-3) rocket motor. The motor was developed for NASA, Langley Research Center, under contract DA-01-021-506-ORD-1269(Z), Modifications 25, 28, 34 and 36 through 42, NASA Order No. L-15,993.

The Castor IIA was developed to replace the Castor I (XM33E5) as second stage of the Scout Vehicle. The Castor IIA provides an increase in total impulse of about sixteen percent as compared to the Castor I through use of a high energy propellant containing 88% total solids in an improved configuration, which increases propellant weight by about 900 pounds. The envelopes and attachment features of the two motors are identical.

The final configuration of the Castor IIA motor is assigned the Thiokol designation TX354-3, and the various models designed and tested will be referred to by the appropriate Thiokol model numbers throughout this report.

SUMMARY

The TX354-3 motor was successfully developed and qualified to meet or exceed all requirements of the NASA development specification, P39-023, as revised, with exception of maximum thrust level. The maximum vacuum thrust of 70,100 pounds exceeds the 70,000 pound upper limit of P39-023 by 100 pounds. A tabulation of PFRT motor performance, including averages which are considered nominal for the TX354-3, is compared with requirements of P39-023 in Table I.

Eight TX354 motors were manufactured under this program. Three motors were tested for development and four were tested for PFRT, two under simulated altitude conditions at Arnold Engineering Development Center (AEDC), Tullahoma, Tennessee. All motors performed satisfactorily. One motor developed a propellant crack during the second low temperature cycle at 20°F and could not be fired. The propellant formulation was subsequently modified slightly to improve physical properties by reducing total solids loading from 89 percent to 88 percent, reducing plasticizer content by one percent, and adding two percent binder. No further cracking problems were encountered. The propellant containing 89 percent total solids was designated TP-H7021. The propellant containing 88 percent total solids was identified as TP-H7025.

One set of motor manufacturing tooling was made.

A nozzle closure capable of withstanding a pressure differential of at least 27.5 psig but not more than 45 psig under static pressure loading was developed separately under contract NAS 1-5124. The closure is molded of Rigithane[1] material and contains a machined failure groove.

An external nozzle insulation blanket made of cork was developed separately under contract NAS 1-4793-1. The insulation blanket maintains nozzle external temperature below 300°F for a minimum of 300 seconds.

CONTRACT OBJECTIVES

The primary objective of this contract was development and limited qualification testing of an improved Castor motor for second stage Scout application. The improvement over the Castor I (XM33E5) was to be realized through use of a highly loaded, high performance carboxyl terminated polybutadiene propellant in an improved configuration. The motor case was to remain unchanged, and the nozzle was to be modified only to the extent necessary for compatibility with the higher energy propellant. Initiators for the ignition system were to remain unchanged. The "Pyrogen" ignition system with exception of the initiators was to be changed to provide the operating characteristics required for the new propellant composition and configuration.

The scope of work can be divided into ten major parts as follows:

Part 1	Motor Design
Part 2	Tooling Design and Fabrication
Part 3	Propellant Tailoring
Part 4	Liner and Insulation Development
Part 5	Ignition System Development
Part 6	Motor Case Hydroburst Test
Part 7	Motor Loading
Part 8	Motor Development Tests
Part 9	Motor PFRT
Part 10	Shipping Container Modification

CONTRACT DESCRIPTION

Procurement of the Castor II development program was initiated through the U. S. Army Missile Command by NASA Defense Purchase Order L-15, 993 and Amendment Number 1 thereto. Contractual coverage was provided to Thiokol by Contract DA-01-021-506-ORD-1269(Z), Modifications 25, 28, 34 and 36 through 42.

---

1. A urethane foam product of Thiokol Chemical Corporation.

Modification 25 was dated 2 October 1963. The scope of work was described in Modification 25 as being the scope set forth in pages 2 through 9 of Thiokol Proposal AHP-38B-63, dated 19 June 1963, and those pages were incorporated into the contract by reference. Technical supervision for the contract was reserved to NASA Langley. NASA development specification P39-023 was referenced as the document setting forth technical requirements. The period of performance was established as fifteen months, setting a contract expiration date of 2 January 1965.

Modification 28 applied addendum number one to NASA development specification P39-023 and set forth requirements for numbers and locations of linear potentiometers for the hydrostatic burst testing of one Castor II motor case. Modification 28 was dated 2 October 1963 and therefore became effective on the same date as Modification 25.

Modification 34, dated 30 September 1964, provided an incremental increase of $130, 000 in funding to cover increases in overhead rates and underestimation of man-hours and materials. The funding increase was requested by Thiokol Proposal AHP-85-64, dated 15 May 1964.

Modification 36, dated 25 November 1964, provided additional funding in the amount of $30, 701 to cover additional work required to make design and manufacturing changes made necessary by the failure in static test of TX354-2 Motor 9. Motor 9 was manufactured under Air Force contract for ATHENA application, but results of the test were directly applicable to the Castor II, since designs of the two motors were identical with exception of the nozzle. The funding increase was requested by Thiokol Proposal HP-134-64, dated 22 September 1964.

Modification 37 provided a funding increase of $113, 029 to supplement the amount provided by Modification 34 and complete funding of the amount requested by Thiokol Proposal AHP-85-64, dated 15 May 1964.

Modification 38, dated 23 February 1965, increased funding by $89, 303 as requested in Thiokol Proposal HP-128-64, dated 3 September 1964, to provide for propellant modifications and manufacture of a replacement for Castor II Motor 2, which developed a propellant crack and could not be tested as a development motor. Modification 38 also extended the period of performance to 2 March 1965 from 2 January 1965.

Modification 39, dated 4 March 1965, directed a change in nozzle exit cone insulation fabrication method from a "rosette" layup to tape winding and provided additional funding of $38, 502 to accomplish the change in scope. The change in scope was proposed in Thiokol Proposal HP-87-64, dated 10 June 1964.

Modification 40, dated 2 March 1965, extended the period of performance to 30 June 1965 as requested by Thiokol letter 64-15552,dated 9 December 1964.

Modification 41, dated 22 April 1965, provided additional funding in the amount of $204, 129. The increase was requested by Thiokol Proposal HP-1-65, dat 13 January 1965.

Modification 42, dated 10 June 1965, extended the period of performance to 30 July 1965 as requested by Thiokol letter 65-04562, dated 24 May 1965.

CONTROLLING DOCUMENTATION

The master technical controlling document was NASA Langley Specification Number P39-023, dated 20 February 1963, entitled "Development Specification for Improved Castor Motor," and Addendum No. 1 thereto, dated 22 July 1963.

The quality control system was controlled by NASA documents NPC 200-2, entitled "Quality Program Provisions for Space Systems Contractors," and NPC 200-3, entitled "Inspection System Provisions for Suppliers of Space Materials, Parts, Components and Services".

SUMMARY OF DOCUMENTATION AND REPORTS

A listing of reports submitted under this contract is shown as Appendix A.

The TX354-3 (Castor IIA) motor as developed is described by the drawings included in Master Parts List AR42300, which is shown as Appendix B. Applicable Thiokol Specifications and Process Standards are shown as Appendix C. A listing of Test and Inspection Procedures is included as Appendix D.

MOTOR DESIGN

Design Summary

The Castor IIA rocket motor uses the 4130 steel case of the Castor I.

The nozzle is a structural member of 4130 steel insulated by ablative plastic materials and having a carbon throat insert. The propellant is in a cylindrical configuration with two radial slots extending essentially to the case wall. Ignition is accomplished through a "Pyrogen" ignition system which is initiated redundantly by two McCormick-Selph M125 Mod 1 electrical initiators. The motor assembly is shown as Figure 1. The loaded case configuration is shown as Figure 2.

The Castor IIA motor is assigned the Thiokol designation TX354-3 and is described in detail in the General Arrangement Drawing and Performance Manual, Thiokol Report No. C-65-4491A. Four models of the TX354 motor were generated, two for Scout application and two for sea level operation on the ATHENA vehicle. The designations are as follows:

TX354-1	Scout
TX354-2	ATHENA
TX354-3	Scout
TX354-4	ATHENA

The TX354-1 and TX354-3 differed only in propellant configuration and nozzle throat area. The TX354-2 and TX354-4 have similar differences. The TX354-1 and TX354-2 share the same propellant configuration; the TX354-3 and TX354-4 have identical propellant configurations. The TX354-1 and TX354-2 are obsolete. The TX354-4 is described in Thiokol Report No. C-65-4492A.

Technical Requirements

Performance requirements for the Castor IIA as set forth in NASA Development Specification P39-023 are compared with actuals as demonstrated in static tests in Table I.

Load conditions which the case and nozzle were required to meet are summarized in Appendix E. In addition, the nozzle was required to have a flexural stiffness equal at least to that of the Castor I nozzle, and to have a moment of inertia of at least 1000 in^4 at each station.

Motor Case Design

The motor case design was not changed from that used in the Castor I motor. The design was checked for compatibility with the required loads and increase in hydrostatic test pressure. The motor case flexural stiffness was calculated as shown in Table II. The locations of stations for determining flexural stiffness are shown as Figure 3. Hydrostatic test pressure of the motor case was increased from 830 psig as used on the Castor I to 910 psig. The increase was made to fulfill the requirement of P39-023 that hydrostatic test pressure be at least 1.15 times the expected maximum pressure at 100°F. The maximum expected pressure, 3 sigma limit, at 100°F is 791 psia. Design burst pressure of the case is 1115 psig.

Nozzle Design

The nozzle design is described by Thiokol drawing R42148. Principal dimensions are shown on Figure 4.

The nozzle was designed to have the same external configuration as the Castor I from the exit plane to a minimum distance of 34.6 inches forward of the exit, as required by Specification P39-023. Interstage connection threads and shear pin holes in the nozzle exit cone are identical to those of the Castor I.

Nozzle flexural stiffness is shown as Table III. Station locations for nozzle stiffness are shown on Figure 5.

The nozzle entrance insulation is Fiberite 4030-190, a compression molded, chopped glass-phenol formaldehyde material marketed by Fiberite Corporation. This material is also used in the Castor I nozzle. The insulation is bonded into the nozzle body with TA-L721, an elastomeric polysulfide-epoxy material manufactured by Thiokol. The TA-L721 acts as a gas seal to prevent flow around the insulation and as a bonding agent to hold the insulation in position.

The throat insert of the nozzle is ATJ grade carbon, which is marketed by National Carbon Company. The outside diameter of the carbon is coated with TA-L721 and wrapped with a thickness of approximately 0.200 inches of "RM Style 41 RPD Pyrotex Felt," a modified phenolic resin impregnated chrysotile asbestos felt marketed by Raybestos Manhattan, Inc. The insert assembly is bonded into the nozzle body with TA-L721. The bonding material also functions as an added safety factor against gas leakage around the insert assembly and between the insert and insulation.

The nozzle exit cone insulation is a tape wound component of resin impregnated, high-silica straight slit tape. The tape is marketed by U. S. Polymeric Corporation as FM-5067. The tape is wound parallel to the nozzle centerline and the part is cured at high pressure and temperature in a hydroclave. The exit insulation is bonded into the nozzle body with RTV88, a silicone adhesive material marketed by General Electric Corporation. The RTV88 material provides excellent temperature resistance, and due to its elastomeric nature, it is an excellent seal against gas leakage around the insulation.

Three significant design changes were made to the nozzle during the course of development as follows:

1. The exit cone insulation fabrication technique was changed from "rosette" layup to tape winding.

2. The nozzle assembly process was changed to permit bonding of the completed exit insulation into the body in lieu of curing the insulation in place in the body.

3. The initial throat area was decreased from 60 to 54 square inches.

Tape winding was substituted for the "rosette" layup after some scalloping and delamination occurred in the exit insulation during the firing of TX354-[illegible] Motor 1, the first development round. It was postulated that the scalloping might induce roll into the motor. It was later discovered that the scalloping and delamination were due to a discrepancy in angle of the "rosette" layup and could have been corrected in the "rosette" configuration. However, the tape wound approach, once instituted, was maintained.

The assembly process was revised to permit bonding of the cured insulation component into the nozzle body after considerable difficulty was experienced with separations between insulation and nozzle body when the insulation was cured inside the body. The separations were presumed to be primarily a result of thermal and cure shrinkage.

The throat area was reduced to decrease gas velocity within the propellant port and to provide increased specific impulse. The reduction resulted from design studies performed after the failure of TX354-2 Motor 9 in static test. Motor 9 was a motor being developed for application to the ATHENA vehicle under Contract AF 04(694)-322. A more detailed discussion of this motor test is included under the heading "Motor Development Tests".

The nozzle is attached to the motor with 32 NAS 150DH30 bolts. A metal-asbestos laminated gasket provides a seal between nozzle and case.

Case Insulation Design

The motor case insulation configuration is shown on Figure 2. The insulation is a trowelable material, TI-O700A, which is produced by Thiokol. TI-O700A has an isocyanate terminated polyurethane and epoxy resin binder system and amine curing agents. The filling agents are carbon, milled glass fiber and dibasic ammonium phosphate.

Development of the insulation composition and methods of application are discussed in detail under the headings "Motor Case Insulation Development" and "Motor Case Liner Development."

The insulation configuration was designed to maintain case external temperatures below about 150°F. The design is conservative in both thickness of insulation and extent of coverage. Insulation is extended in each area at least one and one half web thicknesses to provide a conservative safety margin.

Erosion profiles of motor case insulation from Motors 5 and 22 are shown on Figures 6 and 7. Motors 5 and 22 were fired under simulated altitude conditions, and results from these tests should be representative of expected flight performance of the insulation.

Ignition System Design

The TX362 "Pyrogen" ignition system, Figure 8, was designed and qualified for use in the Castor IIA. Details of the TX362 "Pyrogen" development and qualification are included under the heading "Ignition System Development".

The "Pyrogen" unit is essentially a small rocket motor which is inserted into the forward end of the Castor IIA motor and secured with a retaining ring.

The TX362 was designed to provide satisfactory ignition to the Castor IIA over a temperature range of 30°F to 100°F and under sea level to vacuum altitude conditions. It contains about 2.20 pounds of TP-H7047, a polybutadiene acrylic acid propellant. Characteristics of the propellant are given in Table IV. The case is constructed of helically and circumferentially filament wound epoxy bonded glass. Design burst pressure of the case is approximately 6000 psia. The forward section of the case is reinforced by a stainless steel insert, and the nozzle end is wound over a phenol-formaldehyde, glass filled molded insert which serves as the nozzle throat. A typical "Pyrogen" pressure versus time curve is shown as Figure 9.

The pyrotechnic pellet charge used in the TX362 contains 17 grams of boron-potassium nitrate pellets. The pellets are 0.25 inch in diameter and 0.13 inch in length. Characteristics of the pellets are shown in Table V. The pellets are contained within the adapter by a slotted steel cover. Lead foil bonded to this cover acts as a moisture seal.

Two dual bridgewire electric initiators, Figure 10, are used in the TX362 "Pyrogen". The initiators are marketed by McCormick-Selph Associates, Hollister California, as the M 125 Mod 1, and are described by Thiokol drawing CR38682. The initiators are of the threaded base, header type. Physical and electrical characteristics of the initiator are shown in Table VI.

During motor operation, the case of the "Pyrogen" is melted in the mid-section, and the aft end of the case drops down into the motor. A typical section, recovered from the firing of TX354-3 Motor 6, is shown as Figure 11. On some static test motors, the case end was ejected, and small oscillations in the thrust trace could sometimes be seen at the expected time of ejection. Ejection of the end can be expected in flight motors due to the near vertical orientation of the motor. This ejection is not expected to cause any problem.

Propellant Configuration Design

The propellant configuration of the Castor IIA is a cylindrical port with two radial slots as shown on Figure 2. The configuration was modified slightly during the development program to reduce propellant deformation and gas velocity within the motor. The original configuration, which was used in TX354-1 Motors 1, 2, and 3, and in TX354-2 Motors 8, 9, and 10 (ATHENA Program), is shown as Figure 12. The modified design, shown on Figure 5, which added a 5-inch radius to the aft face of each slot and increased the port diameter by 1 inch aft of the aft slot, was used in subsequent motors.

The pressure and thrust versus time characteristics of the propellant design yield a progressive trace during about the first 25 seconds of motor operation. A typical trace is shown as Figure 13. Addition of a third slot could have provided a more nearly level trace, but the two slot configuration was chosen in conjunction with NASA because it provided an acceptable trace with less complication.

The cylindrical configuration was chosen to provide maximum loading density and web fraction. A large web fraction was desired to provide an extended burning time with the relatively fast burning rates of the highly loaded HC (carboxyl terminated polybutadiene) propellants.

It was recognized from the beginning that mass addition and the resultant pressure drop down the length of the propellant port would be critical considerations in the Castor II propellant design. The configuration was established to use mass addition effect to advantage. The successful test of TX354-1 Motors 1 and 3 and TX354-2 Motor 8 indicated that the selected configuration was well designed. However, TX354-2 Motor 9, the second ATHENA development round and fourth motor to be tested, ruptured on ignition. The failure is discussed in detail under the heading "Motor Development". The resultant analyses and design modifications are presented in detail in Thiokol Report U-65-11A, entitled "An Analysis of the Circumferential Slot Effects on the Internal Ballistics of the TX354 Motor", dated December, 1964. The modifications are summarized here for convenience.

The failure of Motor 9 was caused by a gas flow problem, aggravated by propellant deformation, just aft of the aft slot. It was postulated that propellant deformation around the aft face of the aft slot sufficiently closed the propellant port to produce a velocity of Mach 1 within the motor chamber. The initial propellant deformation was caused by a localized pressure drop, probably greater than 100 psi, around the aft face of the aft slot. The propellant deformation and pressure drop, once initiated, were complementary in effect. The initial pressure drop was inherent in the design and mass addition characteristics of the TX354 motor. The deformation in Motor 9 progressed beyond the point experienced in Motors 1, 3, and 8 because the tensile modulus of the propellant in Motor 9 was significantly less than that of any of the preceeding motors (Motor 9 was the first to use TP-H7025 propellant).

Comparisons of test results of Motor 9 with Motors 1, 3, and 8, which led to a change in propellant configuration, are presented on Figures 14 through 18. The results shown on these figures indicate that the pressure rise rate to about 500 psia was similar for all motors, but that the correlation between head end pressure and thrust started to depart from theory in Motors 1, 8, and 9 beyond 500 psia. A sharp drop in internal pressure down the motor length is indicated by this lack of correlation. Strain gage data confirmed the pressure drop and indicated that the major drop was in the aft half of the motor.

The flow phenomena in Motor 9 that led to the propellant deformation and consequent case rupture were examined by two dimensional gas flow analyses and by experiments using a water table. The water table setup and experimental results are presented on Figures 19 through 25. These results indicate a minor pressure drop around the forward slot of the motor and a significant drop around the aft slot. The effect of increasing the radius from one to five inches on the corner of the aft face of the aft slot is shown as a distribution of the pressure drop over a greater area. This change produces little change in the magnitude of the pressure drop. However, calculations of propellant deflections for various pressure distributions indicate a major advantage from incorporation of the larger radius. Analytical results indicate that, for a pressure drop of 100 psi around the slot, a maximum inward deflection of 1 to 2 inches could occur in the original design, which maintains a one-inch radius on the corner of the slot. A reduction in maximum inward deflection to the range of 0.15 to 0.45 inch with the same pressure drop is calculated when a 5-inch radius is used.

As a result of the failure evaluation of TX354-2 Motor 9 and the subsequent calculations of propellant deflection, the propellant configuration was modified to the design shown on Figure 2. The modifications consisted of increasing the radius on the aft face of each slot from 1 to 5 inches and increasing the diameter of the port aft of the aft slot by one inch, maintaining the original taper. A further modification to the motor design was made to decrease the nozzle throat area from about 60 to 54 square inches. As an additional precautionary measure, for one motor only, the propellant surface forward of the forward slot was inhibited with TA-L721, a polysulfide-epoxy elastomeric adhesive produced by Thiokol. The inhibited surface was effective only on ATHENA TX354-4 Motor 11. Test results from Motor 11 confirmed that the inhibitor was effective but was not required, and the inhibitor was removed from the design.

The changes in port diameter aft of the aft slot and the nozzle throat area effectively reduced gas velocity and the pressure drop along the length of the motor, and the addition of the 5-inch radius distributed the pressure drop over a larger area. The combination of these corrections provided a conservative solution to the propellant configuration design problem.

TOOLING DESIGN AND FABRICATION

The TX354 is compatible with the XM33 handling equipment and harness. However, the insulation and propellant configurations are completely different and require different tooling. One complete set of TX354 tooling was manufactured in support of the development effort. Two additional sets of casting tooling were made for ATHENA, and interchangeable use of the tooling under each contract permitted dual loading of most motors for development and PFRT. All tooling required for TX354 manufacturing is shown on Thiokol drawing AR42416, Tooling Parts List, which is included as Appendix F.

Five significant changes were made to the tooling during the development program as follows:

1. The core aft section, which forms the propellant cavity aft of the aft slot, was redesigned to increase the diameter by one inch as a part of the propellant configuration modifications resulting from the failure of ATHENA Motor 9.

2. Radius formers were designed and made to supplement the forward and aft slot formers and mold a 5-inch radius on the aft corner of each slot. This modification also resulted from the failure of ATHENA Motor 9.

3. The aft dome sweep blade and blade positioner were revised to improve access to the aft dome because of interference of the original design with visibility and the insulation operation.

4. The sweep blades were modified to provide slightly increased clearance to compensate for drag and to add vibrators as part of the changes in insulation application resulting from failure of ATHENA Motor 12.

5. Slot former positioners were designed and built to correct problems which were experienced with canting of the slot former which caused an undesirable slot configuration.

It was necessary to make the TX354 core in three sections because of the necessity of a taper. Slot formers could not be installed over the taper in a one piece core. The core centering and holding devices were then made more elaborate than usual to hold the core sections in alignment while other sections were being added or removed during the propellant casting operation.

A general description of tooling use is given in this report under the heading "Motor Loading".

PROPELLANT TAILORING

The Propellant Tailoring section of this report, which covers pp. 10-19, Tables VII through XIII, and Figures 26 through 65, has been omitted to allow this revised report to be regraded unclassified.

MOTOR CASE INSULATION DEVELOPMENT

Material Selection

The TX354 motor case insulation is TI-O700A, a trowelable material consisting of an isocyanate terminated polyurethane and epoxy resin binder system with amine curing agents and fillers of carbon, milled glass fiber, and dibasic ammonium phosphate. It is applied to the forward and aft domes and slot areas of the case as shown on Figure 2.

The original preliminary design of the TX354 suggested use of TI-L700B (JH-105) insulation which is used in the Castor I (XM33E5). TI-L700B is a trowelable material consisting of a polysulfide polymer and epoxy resin binder system with an amine phenol curing agent and filler of asbestos floats.

TI-O700A was chosen in preference to TI-L700B because of its superior processing properties and erosion resistance, and a presumed superiority in bond compatibility with HC propellants.

A premolded insulation was considered for the aft dome area, where maximum erosion occurs, but sub-scale evaluation tests indicated no real superiority of the premolded material over TI-O700A, and a significant cost increase for pre-molded material could be expected. The material considered was FM-5067B, a phenolic impregnated, high-silica glass material which is a product of U. S. Polymeric Chemicals, Inc.

The three candidate insulation materials, TI-L700B, TI-O700A, and FM-5067B, were tested at various gas velocities in TX24 motors. The motors used TP-H7021 propellant, and a control TX24 motor using TP-H8038 (Castor I propellant) was fired for comparison of propellant effects. The materials were located in the nozzle and adapter as shown on Figure 66. Results were not good because of swelling in the trowelable materials and misalignment of insulation and throat insert in installing FM-5067B. Data are summarized in Tables XIV, XV, and XVI. From the test results, the conclusions can be drawn that TI-O700A is superior to TI-L700B in the higher velocity regions (Mach 0.19 to 0.23) and that FM-5067B offers no significant advantage in comparison with TI-O700A. A valid comparison of the effects of TP-H8038 and TP-H7021 propellants could not be made. TI-O700A was chosen as the motor case insulation material and compatibility studies of bond to grit blasted steel and to TL-H711B liner were performed. Results, which indicated good strengths, are shown in Tables XVII, XVIII, and XIX.

Initial Application Method

In insulating the cases for TX354 Motors 1, 2, 3, and 4 and ATHENA Motors 8, 9, 10, 11, and 12, the conventional method was used. This method involved application of non-deaerated material to the motor case with a spatula, and final contouring with a sweep blade designed to produce the desired configuration. Insulation so applied contains numerous voids, which are not detrimental to insulation properties, but may degrade erosion resistance. The insulation was submitted to only a visual examination prior to lining and loading of the case. Such insulation performed satisfactorily in Motors 1, 3, 4, 8, and 11. However, case burnthrough occurred in the slot area of ATHENA Motor 12. The failure mechanism is discussed further under the heading "Motor Development". Investigations into all possible causes of the failure proved conclusively that the failure was due to faulty application of the insulation and inspection procedures which were inadequate to detect the flaw.

Motor 12 Insulation Failure Evaluation

The motor case burned through at the aft and forward slot locations at approximately six and seven seconds, respectively, after ignition. Subsequent investigations covered the possibilities of inadequate insulation physical properties, unbond, and faulty insulation application.

Three possible modes of failure which could have resulted from inadequate physical properties of TI-O700A insulation were investigated: (1) cracking of the insulation during rapid pressurization, (2) thermal shock, and (3) defects peculiar to the batches of insulation used in Motor 12.

A review of the basic physical properties of TI-O700A insulation is contained in Table XX. It should be noted that these physical properties are for materials tested when aged up to 12 weeks and at temperatures of 0, 77, and 135°F. These values are included for comparison with values to be reported in later paragraphs.

Two samples were cut 180° apart from the aft dome section of Motor 12 after it was tested. These samples were subjected to tensile tests at ambient temperature (Thiokol Chemical Corporation test method) with the following results:

Sample Number	Ultimate Stress (psi)	Ultimate Strain (%)
1	697	29.6
2	1052	34.6

The samples conformed to the curvature of the aft dome section, introducing some error into the test. In addition, the method of testing was not the same as that employed for the results reported in Table XX. However, the values for the samples removed from Motor 12, when reduced to American Society for Testing Materials (ASTM) standards, are considered to be of the same order as those in Table XX.

Samples were taken from the aft dome section of the motor for the tensile tests because of the nature of the failure, which resulted in the aft dome separating from the rest of the case. The insulation in the aft dome section was less affected by the heat generated after the failure. Insulation in other areas of the case (where the initial burn-throughs occurred) was badly charred and not suitable for tensile tests.

For comparison purposes, samples were removed from the aft dome section of Motor 11, which was successfully static tested without hot spots at any point. These samples were tested at ambient temperature, using the Thiokol test method, with the following results:

Sample Number	Ultimate Stress (psi)	Ultimate Strain (%)
1	648	20.0
2	537	22.0

For a further comparison of tensile properties, samples were cut from the insulated case for Motor 5. This case was insulated on 13 August 1964 and had been awaiting loading. Results of these tests, conducted at ambient temperature using the Thiokol test method, are as follows:

Sample Number	Ultimate Stress (psi)	Ultimate Strain (%)
1	948	28.0
2	1735	44.0

A special 10-pound batch of TI-O700A insulating material (Mix LM-2718) was made on 23 October 1964 to simulate as nearly as possible the insulation used in Motor 12. A comparison of the lots of raw materials used in this mix with those used in mixes for Motor 12 is given below. (A complete listing of lot numbers of insulation raw materials used in all TX354 motors loaded to date is given in Table XXI).

Raw Materials	Lot Numbers Motor No. 12	 Mix LM-2718
Adiprene-L	96	96
ERL	68	68
RTA	2427	2495
RTH	2429	2494
MOCA	2422	2518
Carbon	2384	2384
Molacco	2510	2529
Milled Glass	2431	2549
Dibasic Ammonium Phosphate	1944	2492

It was not possible to employ identical lot numbers for all materials because some of the lots used in Motor 12 had been depleted. Tensile specimens were cut from this special mix and tested at ambient temperature, using the ASTM method, with the following results:

Sample Number	Ultimate Stress (psi)	Ultimate Strain (%)
1	925	6.5
2	1290	4.6
3	1429	5.7
4	1299	4.4
Average	1236	5.3

These values are comparable to those given in Table XX.

X-ray film for Motor 12 and all other TX354 motors were examined for evidence of cracks in the insulation. Motor 12 had been subjected to special X-ray examination during the analysis of a canted slot condition in the motor. No evidence of cracks was found. Among the motors examined was Motor 4, which had been subjected to thermal cycling and road testing. This motor, too, was found to be free of any obvious cracks.

The possibility of cracks occurring as a result of unbondedness was considered. It was concluded that a substantial separation of the insulation from the case would have been required to result in enough expansion to exceed the elongation capacity of the material. Thus, it was unlikely that cracking would result from a mere condition of unbondedness without substantial separation from the case. No separation was indicated by X-ray or sonic inspection of the motor. However, the last of these inspections was conducted approximately one week prior to the date of the static test.

The nature of the two burn-throughs in the case of Motor 12 strongly suggested that a small circular area of the case was exposed rather than a long narrow one. The burn-throughs appeared as small, round holes growing with time. This tended to refute an insulation cracking mechanism.

To evaluate the possibility of crack generation by sudden pressurization, the insulated case for ATHENA Motor 13 (which was never loaded) was subjected to dynamic hydrotest (case filled with water and given nitrogen gas surge for rapid pressure build-up). X-ray examination of the insulated case prior to the test revealed that excellent resolution was obtained. No cracks were observed. Maximum pressure of 505 psig was obtained in 111 milliseconds rise time (10 to 90% of maximum pressure). Although the maximum pressure and rate of rise was not as great as desired, they approached the conditions experienced by a motor during static firing. X-ray inspection after the test revealed no cracks.

The effect of high loading rates on the ultimate stress and strain of TI-O700A insulation was determined by conducting tensile tests using specimens from Mix LM-2718. Specimens were JANAF type with 2-inch gage length. The tests were conducted at rates of 0.2, 2.0, 10 and 20 inches per minute, and the data obtained were extrapolated to still higher rates. For the conditions existing upon pressurization, the loading rate in the Castor II motor was considered to be on the order of less than 50 inches per minute. At that rate, the extrapolated elongation would be in excess of 7%, thus meeting the 2.0% required elongation with a safety factor of three and one half. Results of the tests and extrapolated curves are shown on Figures 67 through 70 and in Table XXII.

A review of early tests in the development phase of TI-O700A insulation was made in the interest of considering whether thermal shock might be a factor in potential insulation failure. In its development the material was subjected to both plasma-jet and TX24 nozzle entrance section tests to evaluate its erosion resistance. In these tests no evidence was seen of any tendency of the material to crack through, although some surface crazing and spalling was observed. Samples taken from the aft dome section of Motor 12 after the static test were subjected to oxy-acetylene torch tests and plasma-jet tests. Only surface crazing and spalling were observed in these samples. Samples from the special 10-pound mix of TI-O700A were subjected to the same tests, with the same results.

To determine whether defects peculiar to the batches of insulation used in Motor 12 may have existed, the raw material lots were compared with those used in Motor 11 and in other motors. The lots used in Motors 11 and 12 were identical, although there were variations in the drums used from these lots. (See Table XXI)

The history of the use of TI-O700A insulation in TX354 motor programs was reviewed for changes in formulation of this material. It was found that no deliberate changes were made; however, for Motors 3 and 8 a slight variation occurred because of a misinterpretation of the specified formulation. (Table XXIII) No significant effect would be expected from this small change in formulation.

A search was made for any abnormalities in the preparation of raw materials for the batches of insulation that went into Motor 12. Results of this search indicated that proper procedures were followed and that normal precautions were taken against the effect of moisture. Recorded weights of raw materials added were checked and found to be correct. Except for one batch, all batches were weighed up within a few hours of the time mixing began. The one exception was Mix 14232, which was used in the forward dome of Motor 12. Raw materials for this batch were weighed up four days prior to mixing. Since normal precautions were taken to protect these materials during the four-day period, this delay is not considered to be significant. For a summary of the insulation batches used in all TX354 motors with weigh-up dates, mixing dates and curing dates, see Table XXIV.

Possible mixing variations from batch to batch of TI-O700A were investigated. No significant deviations from standard procedures were found. Temperature histories of the mixes were comparable and normal. There were no significant variations in the order of raw materials added. Batch sizes ranged from 10 pounds to 45 pounds, varying with the portion of the case to which the insulation mix was to be applied. This range of mix sizes for the TX354 motor is normal.

The age of each insulation mix at the time of application to Motor 12 was determined. Except for one mix, the ages were within the normal range of experience. The exception was Mix 14248, which was used to patch both Motors 11 and 12. Its recorded age from completion of mixing to its use as a patching agent for Motor 12 was 330 minutes (5-1/2 hours). At this age the material would be expected to be extremely viscous. It might easily bridge over, with a thin film, a surface crater in the original coat.

Retained weights of insulation in the various sections of the motor were compared with those retained in other motors (Table XXV). Weights in Motor 12 were normal.

The tensile tests of specimens removed from the aft dome of Motor 12 after the static test indicated that there were no abnormalities in the composition of the material represented in that particular batch (Mix 14244).

As a further test to indicate any abnormalities in the insulation applied to Motor 12, composition analyses (homogeneity tests) were run on samples of insulation removed from the aft dome section of Motor 12. Four samples were tested for glass content. The results showed a range from 19.8 to 20.1% of glass.

The possibility that the insulation had become unbonded was investigated. It was hypothesized that if the insulation had been unbonded, the insulation could have been cracked by rapid pressurization during firing, or the flame front could have traveled between the insulation and case, causing burn-through. In order to check out these possibilities, special insulation samples were removed from several cases. Adhesive tests were run, and inspection results were re-examined. It was concluded from all the evidence available that the insulation in Motor 12 was securely bonded in place and that unbondedness did not contribute in any way to the motor failure. Details of this phase of the investigation are described in the following paragraphs.

Special samples were removed from the cylindrical section, under the slots, and from the aft dome section of Motor 12. These samples were used to determine the physical properties of the insulation in the fired case. The fact that it was necessary to cut the samples of insulation from the case with a hammer and chisel indicated an excellent bond.

A sample was removed from the unloaded, insulated case intended for Motor 5. This sample was used to illustrate a void in the insulation extending to the case wall. Although a chisel could not be for this operation because of possible damage to the surface of the case, a sharpened metal spatula and a hammer were needed to cut and pry the insulation loose. Again, an excellent bond was indicated.

Adhesion cup tests were conducted using samples from Mix LM-2718. The average bond strength to grit-blasted steel was 1,116 psi. Each of the four samples broke in the insulation itself, not at the bond interface, indicating that the bond strength was greater than the strength of the insulation. (The lowest stress value obtained was 1,071 psi and the highest was 1,168 psi.)

The radiographic inspection results for Motor 12 were re examined. Tangential radiographs of the insulation interface, taken during the analysis of the canted slot, showed no unbondedness. Tangential radiography is capable of detecting separations greater than 0.010 inch.

A sonic (tap test) inspection was performed on Motor 12 in July, 1964, shortly after the motor was loaded with propellant. No unbondedness was discovered.

Motor 4 was inspected for unbondedness because of the conditions it had undergone: thermal cycling and road testing. This motor was carefully inspected after the failure of Motor 12 using sonic, ultrasonic, and radiographic techniques. No evidence of unbondedness was discovered.

The history of other motors manufactured using TI-O700A insulation was reviewed. Unbonded conditions had been observed in Motors 3 and 9. A separation was noted in each of these motors between the insulation and case at the aft opening. The separation in Motor 3 was a maximum of 7 inches deep along the case wall. The separation in Motor 9 was 1-1/2 to 4-1/2 inches deep along the case wall. Both of these minor separations were repaired by injection of adhesive. Inadequate wetting of the case by the insulation was the cause of the problem. On subsequent motors, immediately prior to application, insulation was "scrubbed" into the affected areas. No other unbondedness was discovered.

The history of the cleaning operation -- grit blasting and degreasing -- for Motor 12 was reviewed. There was nothing unusual in the way this case was cleaned.

The details of the method used in applying insulation to Motors 11 and 12 were carefully scruntinized. Insulated cases on hand were re-inspected to determine the quality of the insulation. A small specimen of insulation was found in the test area immediately after the firing of Motor 12. This specimen contained a void filled with propellant. The results of this phase of the investigation illustrated how voids in the insulation could have led to a failure such as that which occurred in Motor 12.

The seven operators and foremen who actually insulated the cases for Motors 11 and 12 were interrogated. Following is a summary of the findings of this interrogation:

1. The surface of the insulation in both Motors 11 and 12 was, in general, very rough.

2. The extreme aft ends of both motors contained large voids requiring extensive patching. After the patching operations, an attempt was made to radiograph the aft ends of the insulated cases; however, the cases could not be radiographed because a "non-contaminating" inspection procedure had not been developed at that time.

3. The aft dome insulation in Motor 12 was applied initially by a trainee operator. His foreman directed rework of this part of the insulation. The aft slot insulation was installed by the operator considered to be the most adept at applying insulation.

4. The data sheets from Motors 11 and 12 showed that the insulation used to patch voids was 5-1/2 hours old at the time it was used to patch Motor 12. The operators could not confirm or deny this "age". They did say that they did not believe it could have been this old because it would not have been "workable". (A test was run after the failure of Motor 12 to determine whether material of this age could have been applied satisfactorily; the tests indicated that it could have been "worked" but would have been too viscous to obtain a satisfactory application. As has been mentioned previously in this report, subsequent laboratory tests indicated that even though a 7-hour-old patching material might be sufficiently viscous to bridge a void rather than filling it, it still would form a satisfactory bond to the cured material. Values obtained in these tests indicated bond strengths exceeded 1, 174 psi, since all samples tested broke in the material itself rather than at the bond interface, at values ranging from 1,075 to 1, 174 psi.)

The unloaded, insulated cases on hand were re-inspected to determine the likelihood that voids in the insulation which were sufficiently severe to cause motor failure may have been overlooked.

The insulation in Motor 5 contained a void which extended to the case wall. This void was located within 2 inches of a point under the aft slot. Patching of this insulation had not been completed and this void would probably have been filled later, but the mere presence of a void of this type demonstrated the mechanism by which Motor 12 could have failed.

The application of insulation in Motor 15 had been completed, including the patching part of the operations. The insulation in this case still contained a void which extended to the case wall within 2 inches of the location of the aft slot. Still another and more careful inspection of Motor 15 disclosed four additional voids extending to the case wall. At least three voids were detected in Motor 14.

Immediately after the firing of Motor 12, a small piece of insulation was found on the test pad. Propellant had seeped into a void in the insulation to within 1/16 to 1/8 inch of the case side of the insulation. Evidently, the liner covering the insulation had failed to cover this particular void and propellant had entered during casting. In order to be sure that this piece of insulation had come from Motor 12, a laboratory inspection was performed. The insulation contained the correct concentration of milled glass and the same type of liner used in TX354 motors.

Results of Insulation Failure Evaluation

After studying the data accumulated during the investigation, it was concluded that Motor 12 failed because the insulation was improperly applied to the motor case and the inspection technique was inadequate to detect the defects. The insulation contained voids extending from the surface to the case wall. These voids existed in both slot areas and possibly in the head and aft dome sections. At best, the voids in the insulation were superficially covered by a thin coating of patching material. The liner application was also inadequate, since it permitted propellant to penetrate into those voids in the insulation which were not "bridged" over.

The inclusion of voids in swept-in insulation is a usual, rather than a rare occurrence. Porous, swept-in insulations have been manufactured for years without adverse results. In fact, the inclusion of small voids contributes to the thermal resistance of the insulation. It is apparent that the voids in the insulation of Motor 12 were of extraordinary size.

Since it had been demonstrated in past motor tests, there was no doubt that TI-O700A insulation would perform sucessfully if higher standards are implemented for both application and inspection of the insulation.

Insulation Corrective Action

Corrective actions considered fell into four general categories: (1) improvement of flow characteristics of the insulation, (2) improvement in application techniques, (3) tightening of both operating and inspection procedures, and (4) consideration of other methods of insulating cases.

Since TI-O700A insulation had been demonstrated in development tests as well as in four large motor firings as being more than adequate as an insulating material when properly applied, it was decided to continue using the same basic material with two minor modifications to improve its processing characteristics. Variations in the ratio of types of carbon (the ratio of Molacco to Sterling MT) were made to produce a less viscous, probably less thixotropic, material which could be applied with fewer voids.

To improve operating and inspection procedures, the following measures were implemented:

1. Established maximum time limit from addition of curing agent accelerator (RTA) to insulation mix, to the end of the insulation mix.
2. Established maximum time limit from end of insulation mix to end of insulation application to the motor case.
3. Established maximum viscosity limit for insulation to be applied to the case.
4. Established insulation mix temperature limits and optimum temperature for best application properties.
5. Provided for holding insulation batch at this optimum temperature during insulation application.

6. Evaluated possible effects of raw material lot changes on application properties of raw TI-O700A and cured tensile properties. Adjusted formulation (within specified limits) to obtain the best processing properties with new raw material lots.

7. Established maximum insulation cure time to reduce variables in final tensile properties of cured insulation.

8. Started taking samples from each batch of insulation applied in TX354 motors and testing for conformance with minimum tensile requirements.

9. Started extruding deaerated insulation into the case instead of applying with a spatula.

10. Mounted a vibrator on sweep blades to produce smoother surface.

11. Started radiographic inspection of all insulation prior to propellant casting.

Alternate methods of insulation application were considered, and "slinging" was tried. An unsatisfactory surface was obtained. Consideration was given to other types of insulation such as pre-cured rubber insulation, but a change in insulation was not recommended because TI-O700A had been proven an acceptable material when properly applied.

The corrective actions taken to assure proper application eliminated insulation problems as demonstrated by the successful tests of Motors 5, 6, 7, and 22.

MOTOR CASE LINER DEVELOPMENT

The liner used in the TX354 is TL-H711B, which consists of a carboxyl terminated polybutadiene acrylic acid copolymer binder system with imine curing agents and fillers of carbon and titanium dioxide. Composition is as follows:

Material	Thiokol Specification	Weight Percentage
Liquid Polymer (HC)	SP-411	
Liquid Imine Curing Agent, Type I	SP-363	Note 1
Liquid Imine Curing Agent, Type II	SP-363	
Titanium Dioxide	SP-218	Note 2
Carbon Black	SP-20	

Note 1: Total liquids content shall be 60.0 ± 0.5 percent. A 1/1.0 to 1/1.5 equivalent ratio of polymer to curing agents and a 1/2 to 2/1 ratio of curing agents shall be maintained.

Note 2: Total carbon black and titanium dioxide shall be 40.0 ± 0.5 percent. Ratio of carbon black to titanium dioxide shall be 26/14 to 14/26.

The liner is applied to the case by slinging from a rotating disk while the case is also rotating.

TL-H711B was developed prior to start of Castor II development. Evaluation was therefore limited to tests of compatibility of TL-H711B liner with the Castor II propellants and motor case insulation. TP-H7021 propellant was used for the tests since it was anticipated at the time of the tests that all motors would use TP-H7021. The evaluation confirmed that adequate bond prevails between TL-H711B liner and TP-H7021 propellant and TI-O700A insulation. Peel strengths through a 12-week storage time and varying temperatures are shown for TL-H711B to TP-H7021 propellant in Table XXVI and to TI-O700A insulation and grit blasted steel in Table XIX. Adhesive strength of TL-H711B liner to TI-O700A insulation and grit blasted steel is shown in Table XVII. The key to these tables is as follows:

I = Insulation

T = Tab Failure

B = Bond

L = Liner

TCL = Thin Coat of Liner

M = Material

TCM = Thin Coat of Material

When TP-H7021 propellant was dropped in favor of TP-H7025, limited testing was performed to confirm that the slight change in propellant formulation did not degrade the bond of propellant to liner. Results indicated no bond degradation. However, these tests were performed informally and data were not recorded for permanent retention. Subsequent motor loadings, using TL-H711B liner and TP-H7025 propellant, have confirmed adequacy of the bond.

IGNITION SYSTEM DEVELOPMENT

Ignition System Summary

The TX362 Pyrogen system was developed to ignite the TX354 motor. The same system was used in the ATHENA motors, and this report includes the units made and tested for ATHENA since results are directly applicable. Three Pyrogen units were for ignition system development, ten were tested for qualification, and two were tested for batch checks, giving a total of 15 TX362 units tested in addition to those used in motor firings. Eleven Pyrogen units were tested in TX354 motors. (Six pellet assembly tests were conducted in empty or inert Pyrogen units.) The grand total of TX362 Pyrogen ignition systems tested was therefore 26. No malfunctions occurred. Test temperatures ranged from 20 to 120°F, and simulated altitude conditions to 250,000 feet were used.

Ignition System Design

The TX362 Pyrogen unit is shown as Figure 8. Initiators are installed in the Pyrogen only after motor assembly is completed and the motor is prepared for launch. The TX362 uses two McCormick-Selph M125 initiators (Figure 10), the same type initiators which have been used in all Castor I (XM33 Series) motors. The glass fiber case construction of the TX362 is very similar to the TX22-12 which is used in the Castor I and to the case of the Pyrogens used in Pershing motors. The stainless steel adapter of the Pyrogen unit and the pellet retainer are the same, with minor dimensional differences, as used in the Pershing ignition system. The propellant, TP-H8047, is the same as used in all Pershing and Zeus Pyrogens. The boron-potassium nitrate pellets (Table V) are also used in the Pershing and Zeus systems.

Three significant design changes were made during ignition system development as follows:

1. The pellet retainer was changed from a perforated metal disc retained by a snap ring to an integral retainer and disc consisting of a threaded disc with machined slots.

2. The nozzle throat diameter of the Pyrogen was decreased from 1.168 to 1.140 inches after the test of TX354 Motor 1 to increase discharge rate.

3. The burning surface and propellant mass of the Pyrogen unit were reduced on one unit only. The reductions were made by increasing propellant cutback depth to 0.8 inch below the face of the case. The change was made to compensate for a reduction in TX354 nozzle throat area as a part of design modifications subsequent to the failure of ATHENA Motor 9. The change was made to maintain a constant ratio of Pyrogen discharge rate to TX354 motor throat area. The change was effective on ATHENA TX354 Motor 11 only, and the design reverted to the original after the test of Motor 11 indicated that a reduced Pyrogen discharge rate was not desirable.

Pyrogen Case Tests

Each Pyrogen case is hydrostatically tested to 2500 psig for one minute as a part of routine acceptance. To further prove structural integrity of the case design, 5 cases were subjected to tests intended to determine operating limits of the case. Results are presented in Table XXVII.

Three cases were hydrostatically tested to pressures of 6800, 7300, and 8300 psig, respectively. None of the cases ruptured. The cases pressurized to 6800 and 7300 psig started to weep about one inch from the nozzle end, and pressure could not be maintained. The weeping could have been eliminated by using a rubber bag liner in the cases. The case pressurized to 8300 psig was extruded from the test fixture. This type failure is possible in operation, but the pressure level at which it is likely to occur under hydrostatic conditions could be increased through revision of the test fixture.

One case was hydrodynamically tested to 3150 psig in approximately 0.120 second. It was pressurized on a second cycle to 3100 psig in 0.100 second. A second case was pressurized to 3050 psig in 0.060 second. Neither of these cases failed. The maximum pressures achieved exceeded the maximum acceptance pressure of 2000 psia at 120°F by about 50 percent.

Pellet Assembly Tests

Six tests of the pellet assembly were made to prove design of the pellet retention system and obtain pressure data from pellet discharge. Three charges were fired into empty Pyrogen cases, and three were fired into cases containing TI-O700A insulation to simulate free volume of a loaded case.

The three tests in empty cases used the snap ring and perforated disc pellet retainer and pellet charges varying from 16 to 20 grams. When desirable pressure levels were reached, the perforated disc bulged. In the tests of three Pyrogen units using the perforated disc and snap ring, the perforated disc also bulged. The design was then changed to a disc with machined slots and integral attachment threads for retention.

The three tests in cases loaded with a simulated inert propellant used the new pellet retainer and 17 grams of 2D pellets, which became the final configuration. One was fired at 140°F and two were fired at 20°F, all at a simulated altitude of 250,000 feet. Two initiators were used in each of the three tests.

Ignition System Tests

A summary of all Pyrogen units loaded is given in Table XXVIII. Tests of Pyrogen units outside motors and Pyrogens used to ignite TX354 motors are given in Table XXIX.

Pyrogen Units 2 and 3, propellant mixes J-2677-16 and J-2677-17, were the first units to be tested. Serial No. 3 was tested first with 20 grams of 2D pellets. Ballistic performance (Table XXIX) was satisfactory, but the perforated disc retainer bulged and slipped slightly during the test. Serial No. 2 was then fired with 15 grams of 2D pellets. No hardware failure occurred and ballistic performance was acceptable. However, an increased ignition interval was apparent, and the pellet charge for subsequent tests was changed to 17 grams of 2D pellets.

Pyrogen unit Serial No. 1, J-2677-15, was assembled with 17 grams of 2D pellets and used in the static test of TX354 Motor 1 (Table XXIX). Hardware performance was acceptable, and ballistic performance was satisfactory although a reduced ignition interval seemed desirable. Because of earlier problems with the pellet retainer, the design was changed for all subsequent Pyrogens to substitute a one piece threaded retainer with machined slots for the perforated disc and snap ring retainer.

Ten Pyrogen units were then tested for qualification (Table XXIX). These tests demonstrated capability of the TX362 Pyrogen to operate over a temperature range of 20°F to 120°F and at altitudes of up to 250,000 feet.

Two additional Pyrogen units were tested, one each at 70°F and 120°F, as batch check units for propellant mix J-2700, which was made under the ATHENA program.

After the changes in pellet retainer and Pyrogen nozzle throat subsequent to the test of TX354 Motor 1, all Pyrogen units used in TX354 motors were of identical design with exception of Serial No. 20, J-2684-9, which was used in TX354 Motor 11, under the ATHENA program. The propellant surface area and volume were reduced in this unit by machining propellant to 0.8 inch below the face of the case. This change was made to retain the same ratio of Pyrogen discharge rate to motor throat area because of a reduction in the TX354 nozzle area from approximately 60 to 54 inches. Results (Table XXIX) were acceptable but indicated that removal of the propellant from the Pyrogen unit was not necessary.

Detailed discussions of TX354 motor ignitions are contained in each of the applicable motor test reports. The report numbers are listed in Appendix A. A discussion of motor ignition under the PFRT phase is given in this report under the general heading "Motor PFRT".

MOTOR CASE HYDROBURST TEST

To fulfill the requirement of Paragraph 4.3 of NASA Development Specification P-39-023, one Castor II motor case was hydrostatically tested to destruction on 30 January 1964. The test arrangement and results are reported in detail in Thiokol Report U-65-3A, entitled "Test Report, TX354 Rocket Motor Hydrostatic Test Conducted 30 January 1964". Results are summarized as follows:

Pressurization Time	88 seconds
Burst Pressure	1115 psig
Minimum Thickness (actual)	0.100 inch
Minimum Yield Pressure at 0.2% Offset	1040 psig
Ultimate Strength	172.8 ksi
Yield Strength at 0.2% Offset	161.2 ksi
Biaxial Improvement over Uniaxial Ultimate Tensile Strength of Process Control Specimens	7%

Biaxial Improvement over Uniaxial Ultimate Tensile Strength of Specimens Cut from Case	10.1%
Maximum Radial Case Growth at the Centerline of the Cylindrical Section at Design Pressure	0.077 inch

The motor case was manufactured and inspected in accordance with Thiokol Drawing FR35086. The serial number of the case tested was 433. The fabricator of the case was Intercontinental Manufacturing Company of Garland, Texas. The test was successful. It confirmed that the predicted burst pressure of 1085 psia was conservative; the internal pressure at burst was 1115 psig. A satisfactory factor of safety of 1.42 existed between actual burst strength and the maximum expected instantaneous chamber pressure of 788 psia. The measured yield pressure of 1040 psig was 11% above the designed yield value of 940 psig.

The case was conditioned to 70° ± 5°F prior to pressurization using tap water as the pressurizing medium. After initial pressurization cycles for zeroing of instrumentation, pressurization from zero to burst pressure was accomplished in 88 seconds as shown on Figure 71.

Failure was of a ductile shear type which originated approximately 14 inches forward of the center of the cylindrical section. The fracture propagated longitudinally aft for approximately 38 inches and forward for approximately 48 inches as shown on Figures 72, 73, and 74.

No yielding, as defined by the 0.2% offset method, occurred at the design pressure of 940 psig. The calculated PR/t hoop stresses, based on the actual measured wall thickness (t) of 0.100 near the area of initial failure and a case radius (R) of 15.5 inches, are shown below:

	Stress (ksi)	Pressure (psig)
Ultimate	172.8 (calculated)	1115
0.2% Offset Yield	161.2 (measured)	1040

Process control specimens indicated uniaxial strengths as follows:

	Strength, Ksi	
	Ultimate	0.2% Yield
Parent Metal		
Bottom	161.7	150.8
Top	161.4	154.0
Welds		
Bottom	159.0	152.4
Top	159.2	152.7

The case demonstrated a biaxial strength improvement of 7% over the uniaxial ultimate tensile strength of specimens heat treated with the case (process control specimens). The case exhibited a 10% biaxial strength improvement over the uniaxial ultimate tensile strength of specimens cut from the case after burst, Table XXX.

The welds demonstrated ultimate strengths approximately equal to those in the parent metal as demonstrated by the parent metal failure.

Strain gage data were used to calculate the radial case growth in the center of the cylindrical section at the design pressure. The maximum radial case growth observed was 0.5% or 0.075 inch.

The case was arranged for the test in the vertical position with the aft end up. The case was supported at the forward thrust skirt by a wide steel flange. The aft end of the case was held in place by a system of cables to allow free expansion of the case. The aft end of the case was closed for the test with an adapter plate. A dummy Pyrogen head end adapter was used for the forward closure. Pressure was measured in both forward and aft end.

Instrumentation included 72 strain gages; type C-6-121 wire gages by Budd Company; a linear potentiometer, Model 108, by Bourna, Inc.; 3 iron-constantain thermocouples; 2 pressure transducers, 2000 psig capacity by Baldwin Corporation; and 2 Fastex movie cameras, 16 mm, 1000 fps.

Data from several critical strain gages was invalid, and detailed comparison of the test results could not be made with the previous stress analysis (Thiokol Report U-63-4554, entitled "Stress Report for the TX354 Castor II Rocket Motor", dated 10 January 1964, and addendum number 1 thereto transmitted by Thiokol Letter 65-00940, dated 27 January 1965). A representative plot of strain versus pressure is shown as Figure 75.

Linear potentiometers were located in accordance with instructions provided in Modification 28 to the contract to measure forward and aft dome growth and axial case growth between flanges. Potentiometer data was of little value, and meaningful conclusions could not be drawn.

Pressure transducer data were good and were recorded for the full duration of the test.

The Fastex movies showed the burst of the case but were of little value in post-test analyses.

A metallographic study was made on specimens from the center cylinder, the forward cylinder, the center cylinder longitudinal weld, and the girth weld joining the center cylinder and the forward cylinder.

The following conclusions were obtained from the hydroburst test:

1. The structural integrity of the case was verified at the design pressures for pressurization loading.
2. The mode of failure was 100% ductile shear.

3. The origin of failure was approximately 14 inches forward of the center of the cylindrical section in parent material.

4. No yielding, as defined by the 0.2% offset method, occurred at the design pressure of 940 psig.

5. The minimum pressure at which 0.2% offset yield was observed was 1040 psig. This represents a factor of safety of 1.11 over the design pressure and a factor of 1.32 over the maximum expected instantaneous chamber pressure.

6. The maximum radial case growth observed at design pressure was 0.5% of the radius.

7. The case fractured at 1115 psig. This represents a safety factor of 1.42 over the maximum expected instantaneous chamber pressure.

8. The case demonstrated an ultimate strength at burst of 172.8 ksi. This is a 7% biaxial strength improvement over the uniaxial ultimate tensile strength of specimens heat treated with the case.

MOTOR LOADING

Loading Summary

Eight TX354 motors were loaded under this program and five were loaded for ATHENA. A summary of motors made and their disposition is included as Table XXXI.

All motors loaded for Scout development (Motors 1, 2, 3, and 4) and ATHENA Motor 8 were cast singly. All remaining motors were cast in pairs (6 with 7, 5 with 22, 9 with 10, and 11 with 12). Loading in pairs (dual casting) results in a savings of one 300-gallon mix of propellant per pair of motors. A single loading requires three 300-gallon mixes, whereas a dual loading requires only five mixes for the two motors. A typical casting sequence for dual loading is shown on Figure 76.

Loading Procedure

A procedure for insulating, lining and loading the TX354 motor was developed. Modifications were made throughout development as improvements were warranted. The final procedure is described generally in the following paragraphs.

The case is prepared for insulating and lining by being first grit blasted with number 40 steel grit, using an automatically controlled device. The case is then subjected to vapor and spray degreasing with trichloroethylene. The forward insulation sweep blade is installed in the case. Deareated TI-O700A insulation is cast through a bayonet into strips on the forward dome (the case is in a horizontal position and an operator is inside the case). The insulation is swept into the final contour with the sweep blade. The case is rotated slowly and the operator inside the case manipulates the sweep blade with assistance from an operator outside the case. The forward slot area, aft slot area, and aft dome are then insulated in that order by a similar procedure.

Some fairing by vernier blades is required around the aft dome and the Pyrogen boss of the forward dome to achieve final dimensions. The insulation is permitted to remain at ambient temperature for 2 to 4 hours, and the insulation is radiographically examined for voids and thickness. Any voids requiring repair are repaired by completely removing the insulation around the void and filling the resulting cavity with fresh TI-O700A material. Any thickness discontinuity is also repaired. The insulation is then cured for 4 hours at 170°F and a final radiographic inspection is made.

The TL-H711B liner is applied to the entire inside surface of the case by slinging from a rotating disc. The disc is programmed angularly and longitudinally along the case to achieve proper distribution over the domes and cylindrical section of the case. The case may be in either vertical or horizontal position for lining, but the horizontal position is preferred. The liner is cured at 170°F for at least 2 hours prior to propellant casting.

The core for the TX354 is in three sections, and two slot formers are used with each motor. Prior to casting, the motor with fixtures attached is heated in the casting pit to 145°F. The forward section of the core is assembled to the motor, and propellant is pressure cast through four bayonets to the level of the forward slot. The forward slot former and core center section are installed and casting proceeds to the level of the aft slot. The aft slot former and core aft section are then installed, and casting is completed. A centering device holds the various sections of the core in position, and the core position is not disturbed during the various assembly steps. Total casting time per pair of motors usually is 28 to 36 hours.

The propellant is cured at approximately 145°F for 168 hours. The oven heat is then turned off, and the motor is permitted to cool to a temperature of about 100°F prior to core removal.

The core is removed remotely, and the aft propellant surface is machined to the final depth below the aft end of the case.

Slot formers are removed by simply pulling the rope of the formers from the motor.

Propellant Mix Characteristics

Propellant mixes were made large early in the program until experience could be gained with the relatively viscous propellant and the amount of castable waste could be accurately determined. Initial propellant batches were all 4600-pound sizes. It is anticipated that future motors will be cast from one 4000-pound batch, three 3600-pound batches, and one 3400-pound batch per pair of motors. Mix sizes and other mix characteristics for NASA and ATHENA motors are given in Table XXXII.

Motor 2 Anomalies

All motors were loaded without significant incident except Motor 2. A discrepancy in cure temperature occurred during the curing cycle. The discrepancy was considered to be not critical, but it is reported because of the subsequent propellant cracking in Motor 2. An error in desiccation also occurred.

The casting assembly was to have been preheated to 135°F and propellant cure was to have progressed at 145°F. Due to an error in chart placement on the temperature recorder, the casting assembly was preheated to 163°F. The assembly remained at this temperature from 0130 hours when casting started until casting was completed at 1725 hours. The temperature was raised to 173°F where it remained until the error was discovered at 2325 hours. The chart error was corrected, and oven temperature reduced to 145°F at that time.

An error in an engineering order caused Motor 2 to be delivered for temperature conditioning with no desiccant. The error was corrected, and desiccant was placed inside the motor at the end of the first 20°F cycle. It was noted that rather severe frosting of the propellant surface occurred during the inspection, leading, undoubtedly, to water formation when the motor was immediately placed in 110°F conditioning. All subsequent motors were subjected to dry nitrogen purge during inspection at the end of the low temperature cycle.

Propellant Blemishes in Motor 3

A total of six surface blemishes were located 60 to 70 inches from the forward end of the motor case. The blemishes appeared to be uncured areas of propellant, and a crack developed from one of the blemishes. The blemishes appeared to have been caused by entrance of water droplets into the motor at that point during casting. Such an occurrence was quite possible since the casting can elevator had been exposed to rain, and a droplet remaining on the elevator after cleaning could have entered the motor and caused the problem. Five of the surface blemishes were trimmed to a maximum depth of 3/4 inch and were completely removed. The void resulting from complete removal of the sixth blemish and the accompanying crack was 14 inches long by 2-1/2 inches wide with a maximum depth of 1-3/4 inches. The void was tapered gently from each end to the maximum depth at the center of the void. The surfaces of the five smaller blemishes were inhibited by applying two separate coats of TA-L723B liner. The void resulting from removal of the crack was completely filled with PC-15, a slow-burning repair material, after the surface had been coated with TA-L723B, which was cured for two hours at ambient temperature to provide a superior bonding base. Visual and radiographic examination indicated that all repairs were successful. The motor was subsequently tested successfully as the second development motor.

Separation in Motors 3 and 9

Separations between propellant and liner occurred in the forward end of Motor 3, and separations between insulation and case occurred in the aft dome of Motors 3 and 9. The separations were successfully repaired, and corrective action was taken to eliminate the insulation to case separations.

The separation between propellant and liner in the forward dome of Motor 3 extended to a maximum depth of 5-3/4 inches around the Pyrogen boss. The separation was repaired by filling with TA-L705, a repair compound containing 62.8% by weight of Type I Class 3 liquid polysulfide polymer; 33.8% by weight of Type II bisphenol-A epoxy; and 3.4% by weight of amino-phenol (DMP-30).

The separation between insulation and case extended to a maximum of 7 inches in depth and an arc of 170° in Motor 3 and ranged from 1-1/2 to 4-1/2 inches in depth over

60° in Motor 9. These separations were each repaired by filling with TA-L705. The separations were caused by inadequate wetting of the case surface during installation of the viscous insulation. In insulating subsequent motors, the case was thoroughly wetted by scrubbing an initial thin coat of insulation into the case, and the problem did not recur.

MOTOR DEVELOPMENT

Motor Development Summary

Seven motors may be considered as having been tested for development purposes even though only three were called development tests. The three designated as development motors were Motors 1, 3, and 4. ATHENA Motors 8, 9, 11, and 12 also provided valuable data resulting in significant design changes and are, therefore, included in this report. A chronology of motors made and tested is listed in Table XXXI. Details of the test of each motor are shown in the applicable test reports, identifications of which are given in Appendix A. All development motors were fired at 75 ± 5°F, but one, Motor 4, was subjected to two temperature cycles between 20 and 110°F and road tested for 1500 miles prior to firing. Typical pictures of the motors before and after firing are shown as Figures 77 through 80. Performance traces and reduced data are shown for each of these motors as Figures 81 through 99. All motors were fired at Army Missile Command Test Area Five, Redstone Arsenal, Alabama.

Development Test 1, Motor 1

TX354-1 Motor Number 1 was tested on 12 March 1964. Performance was satisfactory and exceeded expected nominal values for the TX354-1 motor. The nozzle was reduced to an expansion ratio of approximately 6.366 to provide near optimum expansion at sea level. The motor contained TP-H7021 propellant (89% total solids). Instrumentation consisted of 3 motor chamber pressure transducers, one Pyrogen chamber pressure transducer, one double bridge thrust cell, 64 thermocouples, 20 strain gages, one triaxial and one biaxial accelerometer.

Two anomalies occurred in ballistic performance of Motor 1. A high peak pressure was experienced at ignition and an unexpected pressure rise just at web burnout occurred. The experienced peak pressure of 691 psia at ignition compared with a normally expected value of about 515 psia. The high pressure was attributed to uncured propellant in the slot areas which eroded rapidly, causing a high pressure peak. When the uncured condition was discovered prior to the test of Motor 1, a peak pressure at ignition of 569 psia was predicted. The slight discontinuity at web burnout was attributed to the propellant shape characteristics which gave an increasing burning surface just at the instant preceeding web burnout.

Ballistic performance exceeded all requirements of NASA Development Specification P-39-023, with exception of maximum thrust. The maximum thrust corrected to vacuum conditions was calculated as 73,200 pounds, which exceeded the limit of 70,000 pounds.

All hardware performed well with possible exception of the nozzle exit cone insulation. This component was a layup of high silica glass formed in a pattern frequently referred to as "Rosette". The angle of the layup was erroneous, as discovered after the test. The nozzle did not fail, but the high silica glass strips delaminated, causing concern about motor induced roll because of the possible rifling effect in the nozzle exit cone (Figure 100). The design was subsequently revised to require tape winding. The ATJ[1] carbon throat maintained integrity, and the erosion rate was only 0.006 in/sec as opposed to an estimated 0.010 in/sec.

The Pyrogen for Motor 1 was TX362 Pyrogen Serial No. 1. The Pyrogen peak pressure of 1415 psia which occurred at 0.029 second after application of the firing current compared with expected results. The ignition delay time of 0.019 second compared favorably with XM33 experience. The ignition interval to 10% of maximum pressure at ignition was 0.085 second and also compared favorably with the XM33. However, the pressure rise rate of 5090 psi/sec from 10% to 90% P_{max} was less than half that usually observed in XM33 motors. This longer rise time was expected as a result of the cylindrical propellant cavity. The Pyrogen case was largely consumed during motor operation as expected, Figure 101.

Good strain and thermocouple data were obtained from the test. No hot spots or other areas of fault or weakness were apparent.

Development Test 2, Motor 3

TX354-1 Motor 3 was tested at 75 ± 5°F on 7 July 1964. The motor chamber was evacuated to a pressure of 0.150 mm Hg absolute prior to ignition. Only one change of significance had been made in this motor as a result of the test of Motor 1 -- the nozzle exit insulation was tape wound, as were those for all subsequent TX354-1, TX354-3, and TX354-4 motors. A part of the nozzle exit cone was removed to provide an expansion ratio of about 10.116. All performance was excellent. The high peak pressure experienced on Motor 1 at ignition was not present. The absence of the peak was attributed to good propellant cure in the slot area of Motor 3. The cure was improved by baking the slot formers for 5 days prior to use to drive off residual volatile materials. Reduced data and performance traces are shown as Figures 84 and 85 A plot of nozzle erosion is shown as Figure 102.

Two problems had been corrected on Motor 3 prior to test, and the test results confirmed that the corrections were complete and successful.

The first problem was partial bond failure between the nozzle body and exit insulation. The insulation had been cured inside the nozzle exit cone, and the separation was apparently caused by thermal and cure shrinkage. Repair was made by injecting a bonding material into the unbonded areas.

The second problem consisted of propellant surface blemishes, six total, culminating in a propellant crack extending from one of the blemishes. The crack and accompanying blemish were removed by trimming an area 14 inches long by 2-1/2 inches wide with a maximum depth of 1-3/4 inches. The resulting void was filled with a slow burning adhesive compound. The remaining blemishes were trimmed to a maximum depth of 3/4 inch, and the surfaces were inhibited with an adhesive material.

---

[1] National Carbon Company.

Development Test 3, Motor 4

TX354-3 Motor 4 was tested at 75 ± 5°F on 5 December 1964. Prior to firing, the motor was subjected to two temperature cycles between the extremes of 20 and 110°F and to a 1500-mile road test. The propellant configuration of this motor was modified by hand trimming as a part of design modifications resulting from failure of ATHENA Motor 9. The motor contained TP-H7025 propellant. Because the integrity of the motor case insulation for this motor could not be guaranteed, the motor was fired on chocks with no thrust instrumentation. However, the motor performed satisfactorily and provided valuable data by confirming that the motor could withstand temperature cycling between the limits of 20 and 110°F and road testing for at least 1500 miles.

In chronology, Motor 4 was the seventh motor tested, since ATHENA Motors 8, 9, 11 and 12 were tested between Motors 3 and 4. Motor 4 was the fifth unit loaded, and the long delay in testing was caused by the time necessary for temperature cycling and road testing and by the problems experienced with ATHENA Motors 9 and 12 which resulted in design changes.

The motor case insulation in Motor 4 was questionable because it had been installed in the same manner and subjected to the same inspection as the insulation in Motor 12, which suffered a burn-through. The loaded motor was subjected to extensive radiographic inspection after failure of Motor 12 to define insulation integrity. It was recognized that faults in the insulation would be partially obscured by the relatively large thickness of overlying propellant, which has an optical density significantly greater than the insulation. Flat shots were made with a Cobalt 60 source in the center of the motor and film on the case exterior to locate suspicious areas. Tangential X-rays were then made for further evaluation of the suspicious areas. Low density areas were located throughout the insulation, but most appeared to be surface irregularity and voids normally found in an insulation applied with spatula and sweep blade. The worst area appeared to be in the aft slot insulation, where a void of 3/8-inch depth reduced insulation thickness to about 1/8 inch in a design thickness of 0.46 inch. Areas of high density appeared in the void area and were assumed to be propellant imbedded in the insulation. A burn-through of the case at 20 to 30 seconds operating time was predicted, but the motor operated satisfactorily for the full duration of the run, and no evidence of overheating appeared.

The propellant configuration in Motor 4 was modified after loading by hand trimming to increase the radius on the aft face of each slot from 1 to 5 inches and to increase the port diameter by 1 inch aft of the aft slot. This modification gave a propellant configuration of the final design for the TX354-3 motor. Ballistic data from Motor 4 added to confirmation given previously in ATHENA Motors 11 and 12 that the propellant configuration modifications gave the desired results of improving gas flow conditions within the motor.

The nozzle of Motor 4 was the second component tape wound with the high silica tape, FM-5067B. Thickness of insulation was reduced below the design level by a machining error, but performance was satisfactory. The actual thickness was 0.73 inch, same as Motors 1 and 3. An erosion profile is shown on Figure 103. Prior to firing, a large separation between the nozzle body and exit insulation was repaired by injection of an adhesive into the unbonded area. Test results indicated that the repair was satisfactory. A part of the nozzle exit cone was removed to provide an expansion ratio of 6.928 for sea level test.

ATHENA Motor 8

TX354-2 Motor 8 was successfully tested for ATHENA at 75°F on 16 July 1964. This was the first ATHENA motor and the third TX354 type motor to be tested. It was fired prior to Motor 4. Motor 8 was the fourth TX354 unit to be loaded, and the last containing TP-H7021 propellant.

Ballistic performance of Motor 8 was considered acceptable, but one peculiarity was evident. Maximum pressure during the first 2 seconds was much higher than expected (828 psia versus about 550 psia) and occurred at 0.55 second, whereas it had occurred at about 0.250 second on Motors 1 and 3. Oscillations in the thrust trace were evident from about 0.58 to 1.05 seconds, and a very slight blip on the pressure trace could be discerned during this period at about 0.59 second. Later review of the ballistics of Motor 8 (after failure of Motor 9) indicated that the long rise to a very high pressure was typical of the characteristics expected of a motor possessing a gas flow problem. Motor 8 was the first unit which should have given a clear warning of the condition which caused the failure of Motor 9. The thrust oscillations were apparently caused by ejection of propellant chunks through the nozzle. Movie coverage was lost due to an electrical system malfunction, and ejection of the propellant could not be positively confirmed. It was further theorized that ejection of propellant chunks relieved the gas flow problem, permitting pressure to return to normal at about 4 seconds. Most likely area from which propellant would have been torn was just aft of the aft slot. Strain gage data confirmed that a large pressure drop occurred down the length of the motor, further confirming probability of a gas flow problem.

Propellant in Motor 8 contained some small cracks which were trimmed from the propellant surface prior to firing. Maximum trimmed depth was 0.75 inch. The repaired areas were coated with an inhibitor, TA-L723B.

The motor case and insulation for Motor 8 performed well. There was no indication of overheating of the case or any other marginal condition associated with the case and case insulation.

The nozzle performed satisfactorily, but erosion to bare metal in the exit cone just aft of the carbon seat presented an undesirable situation. An erosion profile is shown as Figure 104. Testing of Motor 8 did, however, confirm that the Rosette layup was a favorable fabrication technique. Erosion was uniform and smooth, and there was no evidence of delamination such as occurred in Motor 1. Exit insulation maximum thickness had been increased to 0.84 inch as compared with the 0.73 inch in Motors 1 and 3, which had been fired previously.

The exit insulation for the nozzle of Motor 8 had been bonded in during cure, and thermal and cure shrinkage had caused separation of the insulation and steel body over 95% of the surface. The insulation was removed from the body and reinstalled with TA-L721, a polysulfide based adhesive product of Thiokol. The bonding agent performed satisfactorily but reverted due to residual heating after motor burnout and permitted the insulation to drop from the exit cone at about 15 minutes after motor firing.

The Pyrogen ignition system of Motor 8 performed satisfactorily with no indication of marginal conditions. The ignition phase of Motor 8 compared favorably with Motor 1 and 3, and the high peak which occurred in Motor 8 was not associated with ignition characteristics.

ATHENA Motor 9

TX354-2 Motor 9 failed during static test at 75°F on 14 August 1964. This was the fourth TX354 unit to be tested, and the first containing TP-H7025 propellant. The failure culminated in rupture of the motor case near the forward end at about 0.380 second after ignition. The failure was attributed to a gas flow problem aggravated by propellant deformation just aft of the aft slot.

The most significant results of the Motor 9 failure evaluation are presented on Figures 14 through 18. The data from Motor 9 were compared with Motors 1, 3, and 8. The results shown on these figures indicated that the pressure rise to about 500 psia was at a similar rate for all the TX354 motors, but that the correlation between the thrust and pressure started to depart from theory in Motors 1, 8, and 9 at pressures beyond about 500 psia. A sharp drop in internal pressure down the motor length was indicated by this lack of correlation between thrust and pressure. Strain gage data also confirmed the pressure drop and indicated that the major drop was in the aft half of the motor. Movies indicated ejection of propellant from Motor 9 just prior to the rupture.

It was postulated that propellant deformation around the aft face of the aft slot sufficiently closed the propellant port to produce a velocity of Mach 1 within the motor chamber. The propellant deformation was caused by a localized pressure drop, probably greater than 100 psi, around the aft face of the aft slot. The propellant deformation and pressure drop, once initiated, became increasingly severe. The initial pressure drop was brought about by the mass-addition characteristics of the propellant design of the TX354 rocket motor.

The tensile modulus of the propellant in Motor 9 was significantly below the values measured for Motors 3 and 8. The propellant in Motor 9 therefore had less resistance to deformation and permitted continuation of deformation until failure occurred.

The flow phenomena in Motor 9 that led to the propellant deformation and consequent case rupture were examined by two-dimensional gas flow analyses and by experiments using a water table. The water table setup and experimental results are presented graphically on Figures 19 through 25.

These results indicated a minor pressure drop around the forward slot of the motor and a significant drop around the aft slot. The effect of increasing the radius from 1 to 5 inches on the corner of the aft face of the aft slot is shown as a distribution of the pressure drop over a greater area. This change produced little change in the magnitude of the pressure drop. However, calculations of propellant deflection for various pressure distributions indicated a major advantage from the incorporation of the larger radius. The port diameter at this point is approximately 9 inches. Analytical results indicated that, for a pressure drop of 100 psi, a maximum inward deflection of 1 to 2 inches could occur in the original design, which maintained a 1-inch radius on the corner of the slot. A reduction in maximum inward deflection to the range of 0.15 to 0.45 inch with the same pressure drop was calculated with a 5-inch radius.

Because of the failure of Motor 9, only the ignition phase could be fully evaluated. The ignition system performed normally.

ATHENA Motor 11

TX354-4 Motor 11 was successfully tested for ATHENA at 75°F on 24 September 1964. This was the fifth TX354 unit to be tested, and the second containing TP-H7025 propellant. Motor 11 was the first to be tested with design modifications representing the final propellant configuration and nozzle design. It differed from all previous and subsequent motors in that an inhibitor was added to the propellant forward of the forward slot. The inhibitor was added as an additional safety factor to minimize the pressure drop down the length of the motor. The extreme forward 3-inch length of propellant surface was left uninhibited to improve inhibitor breakdown during motor operation by permitting a regulated gas flow over the inhibitor surface. The material used for inhibition was Thiokol material TA-L723A, a polysulfide-epoxy ambient cure material with 8 percent carbon black filler.

Ballistic performance of Motor 11 was satisfactory in all respects. The inhibitor performed as designed. Test results confirmed that the modifications made as a result of the failure of Motor 9 (see discussion under heading "Motor Design") corrected the internal flow and propellant deformation problems which caused failure of Motor 9 and that the inhibitor was not required.

The motor case and case insulation performed satisfactorily with no indication of overheating or other marginal conditions. The nozzle for Motor 11 was the first in which both carbon-phenolic and high silica-phenolic tape wound materials were used to insulate the exit cone. The forward section of the exit cone, from the throat approximately five inches aft, was insulated with carbon-phenolic insulation, and the remaining portion of the exit cone was insulated with high-silica-phenolic insulation. Due to problems of unbondedness with the previous "cured in place" exit cone insulation, the exit cone for Motor 11 was bonded in the nozzle body, after cure, with RTV 88 ambient-cure silicone rubber. A satisfactory bond was obtained. This was the first insulation not cured in place inside the nozzle body.

The output of the TX362 Pyrogen ignition system was reduced to correspond to the reduced motor nozzle throat area of 54 in^2. The ratio of igniter output to motor throat area was the same for Motor 11 as for TX354 motors static fired previously. The Pyrogen propellant cutback was increased by approximately 0.8 inch to accomplish the reduction in Pyrogen output. Performance was satisfactory, but the output of the Pyrogen was subsequently changed back to the previous level, since no indication of over-ignition was present.

ATHENA Motor 12

TX354-4 Motor 12 was tested at 75°F on 16 October 1964. This was the sixth TX354 unit to be tested and the third using TP-H7025 propellant. The motor failed by case burn-through at about 6 seconds. The failure was caused by faulty application of case insulation in the slot areas and inspection techniques inadequate to detect the resulting flaws.

Motor 12 was identical in design to Motor 11 with two exceptions:

1. The propellant was not inhibited at the forward port, since the static test of Motor 11 had established that inhibition was not needed.

2. A standard TX362 Pyrogen igniter was used to ignite Motor 12, whereas the propellant in the igniter used with Motor 11 was cut back to reduce the output.

With these exceptions, all the design changes incorporated into Motor 11 were retained in Motor 12. These changes are described under the heading "Motor Design".

Details of the investigation into the insulation failure of Motor 12 are contained in this report under the heading "Motor Case Insulation Development".

Performance of Motor 12 prior to burn-through was normal and further confirmed that the design modifications made subsequent to failure of Motor 9 had successfully eliminated the gas flow and propellant deformation problems which caused failure of Motor 9. Theoretical motor head-end pressure and thrust are compared on Figure 105 with results from Motors 11 and 12. Figure 106 compares motor chamber pressure versus time during the ignition phase of Motors 1, 3, 8, 9, 11, and 12.

MOTOR PFRT

PFRT Summary

Four motors were successfully tested for PFRT. These were Motors 7, 6, 5, and 22, which were fired in the order listed. Motor 7 was tested at 20°F at Redstone Arsenal, Test Area Five, on 31 January 1965. Motor 6 was fired at 110°F at Redstone Arsenal on 1 March 1965 after exposure to two cycles from 20 to 110°F. Motors 5 and 22 were tested at approximately 75°F under simulated altitude conditions at AEDC. Motor 5 was fired on 26 April 1965 and Motor 22 was tested on 30 April 1965. All PFRT motors were of identical design, but the nozzle exit cones were cut off on Motors 6 and 7 to provide an expansion ratio for each motor of approximately 7.05. Performance of the four units is compared in Table I. Reduced data and plots for each motor are shown on Figures 107 through 118.

The interior of Motor 7 was evacuated to a pressure simulating an altitude of approximately 200,000 feet to provide a simulated altitude ignition. Only one initiator was used in Motors 6 and 7. The use of one initiator in static test is customary to prove redundancy. However, two initiators were used in each of Motors 5 and 22 to more realistically simulate flight performance. Some difficulty was experienced with AEDC altitude simulation equipment, but the average simulated altitude for Motors 5 and 22 appeared to be about 78,000 feet and 98,000 feet, respectively.

All motors performed well with no indication of any hot spot or other trouble area.

PFRT Propellant Ballistics

The effective ratio of specific heats for TP-H7025 propellant was changed from 1.12 to 1.16 as a result of PFRT testing under different altitude conditions.

A propellant ratio of specific heats of 1.12 was used for internal ballistic calculations prior to the simulated altitude tests of Motors 5 and 22. This value was a result of theoretical thermochemical calculations which determined a ratio of specific heats necessary to make the exhaust gas temperature and pressure ratios between the combustion chamber and nozzle exit conform to the law of isentropic flow. After the static tests of Motors 5 and 22, it became evident that the effective ratio of specific heats did not agree with thermochemical calculations since the value of 1.12 could not be used to correlate sea level and altitude performance of the TX354-3 motor. Therefore, the value of ratio of specific heats of 1.16 was determined using static test data a sea level and altitude conditions. The value of 1.16 is the effective ratio of specific heats necessary to correlate TX354-3 motor impulse at sea level and altitude conditions. This empirical determination was based on the ballistic performance of TX354 Motors 5, 6, 7, 11 and 22 and was preferred over the thermochemical calculations for evaluating the performance of the PFRT motors.

The temperature coefficients of chamber pressure and burning rate used in correcting the ballistic test data of the PFRT motors to reference conditions were determined from TX3 ballistic test data. These data were taken from thirty-five mixes of TP-H7025 propellant representing approximately 280 TX3 motors. The nominal values of chamber pressure and burning rate coefficients determined were 0.00090/°F and 0.00085/°F, respectively. A nominal burning rate exponent (n) of 0.274 was also determined from the same data.

PFRT Propellant Physicals

All PFRT motors were loaded from common batches of propellant raw materials. The equivalence ratios of acids to imines were changed between the loading of Motors 6 and 7 as a pair and 5 and 22 as a pair. The equivalence ratio was changed from 1/.85 in Motors 6 and 7 to 1/.84 in Motors 5 and 22. The change was made to provide a propellant with greater elongation. Average physical properties are compared to the limits then applicable in SP-523 as follows:

Parameter	SP-523 Limit (Minimum)	TX354-3 Motor 7 and 6	TX354-3 Motor 5 and 22
Modulus, psi (77°F)	200	450	600
Strain at Maximum Stress (20°F, in/in)	0.20	0.221	0.232
Maximum Stress, psi (77°F)	50	76.2	82.8

The shift in stoichiometry apparently gave the desired effect, even though the differences were quite small.

PFRT Ballistic Performance Evaluation

PFRT motor burning rates versus TX3 burning rates were as follows:

Motor Number	Temperature (°F)	TX3 Burning Rate (in/sec.)	Large Motor Rate (in/sec.)	Scale Factor
5	72	0.28568	0.30587	1.07067
6	110	0.29633	0.31446	1.06118
7	20	0.27408	0.29429	1.07374
22	78	0.28723	0.30715	1.06935

The measured PFRT nozzle throat and exit diameters before and after firing are as tabulated below:

Motor Number	Throat Diameter (in.) Before	Throat Diameter (in.) After	Exit Diameter (in.) Before	Exit Diameter (in.) After	Expansion Ratio Average
5	8.289	8.536	38.505	38.589	20.996
6	8.291	8.508	22.205	22.513	7.051
7	8.289	8.522	22.205	22.433	7.054
22	8.290	8.515	38.503	38.689	21.099

A slight difference existed between the AEDC and Thiokol nozzle throat and exit diameter measurements of Motor 5 and 22. The above are Thiokol measurements.

Comparative results of all major performance parameters are summarized in Table I. In comparing performance parameters, the data from Motors 6 and 7 were corrected to vacuum conditions and an expansion ratio of 20.95, whereas data for Motors 5 and 22 are actual.

PFRT Ignition Evaluation

A TX362 Pyrogen ignition system conforming to Thiokol drawing R41728 was used to ignite the TX354-3 PFRT motors. The TX362 is a head-end mounted Pyrogen igniter which incorporates an epoxy-impregnated fiberglass case loaded with TP-H8047 propellant in a twelve point internal-burning star configuration. One CR38682 (M 125 Mod.1) electric igniter and a 17-gram booster charge of BR25400 (2D) pellets were used to ignite the Pyrogen units in Motors 6 and 7. The ignition systems for Motors 5 and 22 were identical to these except that two CR38682 initiators were used. The over-all ballistics and hardware performance of the Pyrogen igniters were satisfactory. The ignition times of all motors were satisfactory.

The pre-ignition conditions within the propellant cavity of Motor 7 were 20°F, 56% R. H., and 0.240 mm Hg. This was the first motor tested at 20°F and the second motor tested at simulated altitude for ignition.

The igniter contained 2.153 pounds of TP-H8047 propellant and produced a normal peak pressure of 1355 psia which occurred at 0.015 second after command (application of voltage to the firing circuit). Initial pressure rise in the igniter occurred at 0.005 second from command, and igniter web burn-out occurred at 0.283 second from command, which was typical for previous igniter tests. The actual igniter burning time of 0.278 second was also typical. The following motor ignition data were obtained:

Ignition[1] Delay (second)	Ignition[2] Interval (second)	Ignition[3] Interval (second)	Rise[4] Time (second)	Maximum[5] Pressure (psia)	Average Pressure (psia)
0.170	0.185	0.237	0.052	495	609

1. Time interval from command to first pressure rise.
2. Time interval from command to 10% of maximum pressure.
3. Time interval from command to 90% of maximum pressure.
4. Time interval from 10% of maximum pressure to 90% of maximum pressure.
5. Maximum head-end motor chamber pressure occurring during ignition phase.

The absence of an indication of pressure rise in the motor chamber before 0.170 second is unusual (Figure 115). In previous tests of TX354 motors and of most other large motors utilizing Pyrogen igniters, there has been an initial premotor-ignition rise in pressure in the motor chamber of some 20 psig caused by the igniter gases. A possible reason for the absence of an indication of motor chamber pressurization by the igniter is that an entrapped air bubble in the transmission line for the high frequency pressure transducer (gage BPC #17823) pushed the oil out of the line upon reduction of motor chamber pressure to 0.240 mm Hg. Without oil in the line, the response of the pressure gage to initial pressure rise was delayed by the cushioning effect of the "air" left in the line.

The ignition intervals of 0.185 second and 0.237 second to 10% and 90% of maximum pressure respectively were longer than those of Motor 3 (0.140 second and 0.222 second) fired under simulated altitude conditions and 75°F. This was due to the combination of altitude pressure and the lower motor propellant temperature of 20°F for Motor 7. There was still a comfortable safety factor for ignition in that approximately one-third of the Pyrogen propellant was left to burn after the motor was ignited (the motor is considered to be ignited beyond the point of extinguishment when motor chamber pressure has reached approximately 10 to 15% of its maximum value).

The over-all ballistics and hardware performance of the Pyrogen igniter were satisfactory. Motor ignition at the most extreme combination of Castor II-A environmental conditions (20°F and 0.500 mm or less of Hg) was satisfactory.

TX354-3 Motor 6 and igniter were temperature cycled between 20 and 110°F over a 25-day period prior to static firing at 110°F. The igniter contained 2.156 pounds of TP-H8047. The following motor ignition data were obtained:

Ignition[1] Delay (second)	Ignition[2] Interval (second)	Ignition[3] Interval (second)	Rise[4] Time (second)	Maximum[5] Pressure (psia)
0.008	0.067	0.130	0.063	530

The ignition intervals of 0.067 second and 0.130 second were the shortest intervals for any TX354 motor tested to that time, and the ignition portion of the pressure-time trace was virtually identical to the trace for Motor 4 tested at 75°F with exception of the slightly shorter ignition intervals. Motor ignition was completely satisfactory.

The igniter peak pressure of 1995 psia and burning time of 0.225 second were within the specification (SP-526) limits of 2000 psia maximum and 0.220 second minimum, respectively; however, the shape of the igniter pressure-time plot indicated that the igniter operated differently from previous units. The igniter pressure dropped from the initial high peak to a level higher than the operating pressure levels of the other units tested from propellant mix J-2700. But, instead of slowly regressing to web burn-out, the pressure continued to drop rapidly.

Several possible causes of this unusual operation were considered. The most likely cause of the high peak pressure and subsequent rapid pressure decay is believed to be the failure of some portion of the propellant-to-liner bond system at the aft end of the loaded Pyrogen case. One propellant-to-liner separation was found during visual inspection of the unit. As described by Thiokol Discrepancy Report 03377 and Rework Report 00828, the 1-1/2 inch deep (longitudinally) by 1-inch long (circumferentially) separation was behind three major and three minor crests and was repaired by injecting TA-L705 adhesive into the separation with a hypodermic needle. The unit was again visually inspected and accepted for use. However, other separations could have existed in the aft end of the loaded case.

The igniter is believed to have operated as follows. Upon initiation of the unit, a small piece or pieces of propellant crests separated or lifted from the unit. The combination of increased surface area and the reduced port area due to the raised propellant caused the initial high peak pressure. Once "steady state" operation was obtained after the initial peak pressure, the separated propellant burned on both sides as evidenced by the approximately 100 psia higher-than-normal pressure beginning at about 0.060 second after initiation and ending at about 0.110 second which was half the web burning time of the remaining unseparated propellant.

TX354-3 Motor 5 was conditioned at 75°F and static fired at a simulated altitude (pressure of 23.1 mm Hg). The igniter contained 2.155 pounds of TP-H8047 propellant. The igniter had a normal peak pressure of 1640 psia which occurred at 0.025 second after command (application of voltage to the firing circuit). Initial pressure rise in the igniter occurred at 0.013 second from command, and igniter web burn-out occurred at 0.293 second from command. The following motor ignition data were obtained:

Ignition[1] Delay (second)	Ignition[2] Interval (second)	Ignition[3] Interval (second)	Rise[4] Time (second)	Maximum[5] Pressure (psia)
0.013	0.082	0.153	0.071	482

TX354-3 Motor 22 was conditioned at 75°F and tested at a simulated altitude (pressure of 91 mm Hg). The igniter contained 2.150 pounds of TP-H8047 propellant and had a normal peak pressure of 1500 psia which occurred at 0.025 second after command (application of voltage to the firing circuit). Initial pressure rise in the igniter occurred at 0.15 second from command, and igniter web burn-out occurred at 0.292 second from command. Motor ignition data were obtained as follows:

Ignition[1] Delay (second)	Ignition[2] Interval (second)	Ignition[3] Interval (second)	Rise[4] Time (second)	Maximum[5] Pressure (psia)
0.007	0.087	0.157	0.070	495

PFRT Unburned Propellant

A narrow intermittent band of unburned propellant approximately 4 inches wide remained in PFRT Motors 5 and 22 after firing. Both of these motors were static fired at simulated altitude conditions at AEDC. The remaining propellant measured approximately one pound in Motor 22 and was estimated to be approximately 0.1 pound in Motor 5. This band of propellant existed just aft of the forward motor case slot insulation which represents the last burning segment of the TX354 propellant configuration. A small amount of unburned propellant had remained previously in XM33E5 Motor 156 after being static fired at similar conditions at AEDC. Propellants such as used in the TX354-3 and XM33E5 motors will extinguish and not reignite at pressures below 1.0 psia.

PFRT Inert Parts Evaluation

All inert parts performed satisfactorily. Motor case erosion profiles for Motors 5 and 22, fired under simulated altitude conditions and thus representative of expected flight performance, are shown on Figures 6 and 7. Nozzle erosion profiles for these two tests are shown as Figures 6A and 7A.

NOZZLE CLOSURE DEVELOPMENT

A nozzle closure which would retain an internal motor pressure of at least 27.5 psig and rupture at not greater than 45 psig under static loading was developed for the Castor II under Contract NAS 1-5124. The closure was molded of Rigithane[1] foam and was a slight modification of the Castor I closure. Twelve closure burst tests were conducted under static pressure loading conditions. The first seven were development tests, and the remaining five were for qualification. Three tests were conducted in motor

---

[1] Rigithane is a urethane foam material produced and marketed by Thiokol Chemical Corporation

firings. Two bonding materials were evaluated for mounting the closure in the exit cone, but only one, RTV 88[1], was considered satisfactory.

The closure design is shown on Figure 119 (drawing R42653).

Closure configuration and density were limited by the existing closure mold, the use of which was required by Paragraph 2.4 of Statement of Work L-5508, which was included in Contract NAS 1-5124.

The closure was designed to a density of 20 pounds per cubic foot, the maximum density which could be reproducibly made with the existing mold and Rigithane material. It was theorized that the more dense material would be relatively brittle and therefore would exhibit less difference in dynamic burst pressure as compared to static conditions. Previous experience with a closure in the density range of 10 pounds per cubic foot had demonstrated a burst pressure under rapid rise conditions approximately three times the burst pressure under static pressure conditions.

The closure was designed to require machining of the bond surface to provide a half angle of 22 degrees, 37 minutes, to match the nozzle exit cone and to assure a reproducible bond surface. A groove is required in the forward face of the closure to induce failure at the desired pressure, and the aft face of the closure is machined to remove mold rind and to provide a reproducible thickness of material remaining after machining the groove.

Fifteen closures were manufactured. Molding to the 20 lb/ft^3 density required placement of the mold in a press and holding of force on the mold for several hours. Maximum production in the single available mold was one closure per day. The failure groove, aft face, and bonding surfaces were machined during the development phase only after results of each preceeding test had been evaluated. All qualification closures were made identically within normal manufacturing limits. Qualification test results, therefore, should be representative of expected reproducibility in production closures.

Development and static pressure qualification results are summarized in Table XXXIII. The configurations tested are shown as Figures 120 through 124.

Each closure was bonded into the exit cone of the fired nozzle from Castor IIA Motor 7. The insulation remaining in the fired exit cone was machined to provide a firm bonding surface. However, the insulation thickness remaining was small, and the insulation started to fail after the second test. After the fifth test, the insulation was removed, and the remaining closures were bonded directly to the steel nozzle body.

Pressurization was provided from a manually controlled nitrogen bottle, and pressure was recorded visually, by a minimum of three persons, from a dial gage for each test.

Each closure failure originated at the center of the aft edge of the failure groove and progressed at roughly 45° to the aft face. Photographs were not taken.

---

1. A silastic material marketed by General Electric Corporation.

Two materials which are commonly used for bonding closures were tested. RTV 88, a silastic material marketed by General Electric Corporation, was the superior material. Scotchcast, a 3M material, did not perform satisfactorily. However, Scotchcast is available in a variety of mixtures, and it could, undoubtedly, be qualified for use in the Castor IIA with additional testing. Only one test was conducted with Scotchcast. RTV 88 is more easily applied.

Two closures of the final design were tested in static firings of Castor IIA motors. One closure of an interim design, E. O. CR30563-C, SN 004 (Figure 122) was tested in the static firing of TX354 Motor 6. Results are summarized in Table XXXIV. The closure in Castor IIA Motor 6 was not equipped with a pressure transducer because the Government-supplied transducer was not received in sufficient time to permit incorporation into the test. The closures in both Motors 5 and 22 were equipped with 200 psi Statham transducers. Closures in each of the three motors were also instrumented with breakwires. Complete instrumentation details are included in the applicable motor test reports.

NOZZLE EXTERNAL INSULATION DEVELOPMENT

External Insulation Summary

An insulation made of cork was designed and tested under Contract NAS 1-4793, Task Order No. 1, on two Castor IIA motors, 5 and 22, fired under simulated altitude conditions at AEDC. The material was compared with other materials on the nozzle of Castor IIA Motor 7, which was fired at sea level. Data from the tests at AEDC were obscured beyond 40 to 100 seconds. External temperature of the insulation blanket under vacuum conditions was calculated from assumed heat input based upon data from the sea level test of Motor 7. Calculations are considered conservative. Characteristics of the cork material are as follows:

1. Thermal conductivity at 100°F	0.40 - 0.60 $\frac{BTU}{hr\ ^\circ F\ ft^2/in}$
2. Specific heat	0.40 - 0.60 $\frac{BTU}{lb\ ^\circ F}$
3. Specific weight	30 ± 2 lb/ft^3
4. Heat of ablation, convection, min.	1400 BTU/lb
5. Heat of ablation, radiant, min.	3000 BTU/lb

The insulation design conforms to limits presented in Sketch 1 of the Work Statement, Contract NAS 1-4793-1. The design is shown on Thiokol drawing R4274 (Figure 125).

Thermocouple Data

The recording of valid data on the nozzle exterior of Motors 5 and 22 was hampered by the presence of steam and water vapor in the test chamber during most of the time of interest (500 seconds). The following general comments related to the valid recording intervals were established:

Recording Time	Validity
0 to 40 or 50 sec	All data good
40 to 100 sec	Some data affected by water and steam
100 to 240 sec	All data invalid
240 to 1040 sec	Some channels recorded but possible base line shifts occurred

Therefore, only 40 to 100 seconds of accurate data for either the steel nozzle or the exterior of the cork were obtained from the AEDC tests. This fact indicated that heavy reliance must be placed on a predicted temperature for the exterior surface of the cork. During the 40 to 100 seconds of valid thermocouple data, the following observations were made:

1. The measured temperatures on the steel nozzle exterior during the first 100 seconds for Motor 5 under simulated altitude conditions agreed well with data from similarly located thermocouples on Motors 1 and 7, which were tested at essentially sea level pressure (Figure 126). The temperature was higher for Motor 1, as expected, because a hotter propellant and an exit insulation of less thickness were used, resulting in exposure of bare metal on the nozzle interior during the later stages of motor operation.

2. The highest temperature on the steel nozzle exterior during the first 100 seconds occurred, as expected, at the aft-end of the nozzle insert.

3 The highest cork blanket outer radius temperature measured during the first 40 to 50 seconds of valid data was a 15°F temperature rise on TC No. 47, Motor 5.

4. For some of the thermocouples on Motors 5 and 22, the direction of change of the temperature (i.e., either increasing or decreasing) was probably valid in the region beyond 240 seconds. Therefore, the temperature on the steel nozzle exterior was probably still gradually rising at the end of 500 seconds for the altitude test.

Temperature Prediction for Exterior of Cork

To obtain an indication of the effectiveness of cork in preventing heat release from the exterior side of the nozzle throat region, an assumed "worst case" was chosen for heating of the cork at its internal surface. The original intention for the temperature prediction was to take the highest temperature thermocouple data on the steel exterior of the nozzles tested under simulated altitude conditions (Motors 5 and 22) where no free convective cooling currents were present, assume this steel nozzle temperature was also the temperature of the inner wall of the cork, and input this temperature history as the driving function to obtain the exterior temperature of the cork by a transient heat conduction analysis. Unfortunately, none of the data from Motors 5 and 22 were worthy of use as the driving function for an analytical temperature prediction.

Data from temperature measurements of the steel exterior of the nozzle at atmospheric pressure, where free convection and residual burning of the motor occurred, were used. The steel nozzle data for atmospheric tests (Motors 1, 6, and 7) did agree with the altitude test data for the first 100 seconds (Figures 126 and 127). For a first prediction, the temperature data for the steel nozzle at atmospheric pressure was input as the thermal driving function. (This implicitly assumed that the convective cooling effect was less than, or equal to, the residual heating effect if the hottest atmospheric data were also assumed to be the hottest altitude temperature data).

The highest steel nozzle exterior temperature of Motor 7, shifted from an initial temperature of 35 to 70°F, was used as the "worst case" driving temperature to predict the exterior temperature of the cork. The cork temperature was predicted by a computer program (No. 6174) utilizing a one-dimensional, variable property, non-ablative, transient heat conduction analysis. Thermal properties for the cork were obtained from AIAA papers No. 64-356 and 65-117.

Figure 127 displays the results of the cork temperature prediction for the highest temperature location. Little change occurs in the cork outer surface temperature for the first 125 seconds, after which the cork temperature gradually rises to 380°F by 500 seconds of lapsed time. These calculations should provide conservative results since the temperature of a steel nozzle body under vacuum conditions is unlikely to reach that experienced at the highest temperature region of Motor 7.

The predicted temperatures of Figure 127 are considered to be valid "first look" data.

Comparative actual curves are shown as Figures 128 and 129 for sea level test of Motor 7.

SHIPPING CONTAINER MODIFICATION

The Castor I (XM33E5) shipping container design was modified to accomodate the increased weight of the TX354. A detailed analysis of the container and the degree of protection provided to the TX354 is given in Thiokol Report U-65-4483, entitled "Special Report, Shipping Container Analysis Castor II TX354", undated. Two containers were modified for shipment of Motors 5 and 22 to AEDC.

A container was subjected to a 1,500-mile transportation test utilizing TX354 Motor 4, which was subsequently successfully static fired. The container performed satisfactorily. Data from the transportation test are reported in Thiokol Report, "Test Report, TX354-1 Rocket Motor Number 4, Development Test 3", dated 25 September 1964, Castor II Program, Contract No. DA-01-021-506-ORD-1269(Z).

The shipping container for the TX354 rocket motor is basically a modification of the XM33E5 shipping container and is described by Thiokol Drawing JR41810. It is a reusable container of durable sheet metal clam shell construction reinforced with structural steel. This container provides protection for a completely assembled TX354 motor. Shipping straps are supplied with the container to adequately secure the motor in the container during shipment. The container is weather resistant for storage of its contents and utilizes a shock mount suspension system within the container to protect the contents from damage during handling. The container will adequately protect the TX354 motor during shipment by rail, truck, aircraft, or ship, and during a 12-inch end rotation drop. The natural frequency of the container suspension system is 6.8 cycles per second, which is within the critical frequency range of 2 to 7 cycles per second. However, this natural frequency is considered acceptable because of the high damping characteristic of the shock mounts used.

The modifications made to the XM33E5 container to adapt it for the TX354 motor are as follows:

1. Provisions were made to incorporate the use of "T" bolts (MS9204-14) for rapid removal of the container top half or lid. By turning the head of the "T" bolt 90 degrees, the rectangular head will drop through a 1.1 x 0.69 hole in the top half of the container such that it no longer secures the two halves.

2. The eight shock mounts used in the XM33E5 shipping container (Lord[1] J-5131-1) were replaced by twelve Lord J-5391-20 mounts. A comparison of shock mounts shows the shock mount in the XM33E5 container with the TX354 motor to be overloaded by about a factor of 2. In addition, the spring constant was too low with these shock mounts, resulting in a natural frequency of 4 cps which is highly undesirable. Therefore, a new suspension system was required for the TX354 container.

3. Structural channels were added to the container between the skids to allow lifting with a fork lift. Structural reinforcement of the container was made between the skids such that the fork lift channels could be added and used without damage to the container.

4. Lifting holes were added to the bottom hald of the shipping container for the express purpose of lifting the container with the TX354 motor installed. The words "Lifting Lugs for Lid Only" were added adjacent to the lugs on the top half since they are inadequate for handling the loaded container.

5. A documentation tube was added to the shipping container assembly in the forward dome of the container. The tube has end caps for easy access to motor documents. Stenciling adjacent to the tube on the container dome clearly indicates the location of the motor records.

6. The pressure relief valve was removed. It is not necessary since the container has open drain holes and could not be pressure sealed during air transportation.

---

1. Lord Manufacturing Company, Erie, Pennsylvania.

7. Drainage holes were added in the container as an additional precautionary measure. Two 1.5-inch diameter holes were made at each end in the bottom half of the shipping container.

The container shock mount system before (XM33E5) and after (TX354) modification is presented as follows:

	XM33E5 Container	TX354 Container
Type Shock Mount	J-5130-1	J-5391-20
Number of Mounts	8	12
Spring Constant/Mount	1700 lb/in	3000 lb/in
Dynamic Spring Constant/Mount	----	3900 lb/in

	Maximum Calculated	Maximum Recommended By Lord	Maximum Calculated	Maximum Recommended By Lord
Static Load/Mount	1225 lb.	600 lb.	440.4 lb.	800 lb.
Static Deflection	0.72 in.	---	0.294 in.	---
Dynamic Deflection	4.16 in.	2.5 in.	2.126 in.	5.00 in.
Natural Frequency	3.7 cps	avoid 2-7 cps range	6.8 cps	avoid 2-7 cps range
Acceleration Loading about Motor C.G.	6.8 g's	---	8.40 g's	---

CONCLUSIONS

The Castor IIA motor meets or exceeds all requirements of NASA Development Specification P39-023 with exception of maximum thrust. The average value of 70,100 pounds maximum thrust demonstrated in PFRT motors exceeds the upper limit of P39-023 by 100 pounds.

The motor was successfully developed with three static tests. Additional testing of four motors for the Air Force under the Athena program provided further valuable development information. Performance of the final design, the TX354-3, was proven in four Preliminary Flight Rating Tests over a temperature range of 20° to 110°F. Structural integrity was further proven by a 1500 mile road test. Operation under high altitude conditions was evaluated and proven by the test of two motors under simulated altitude conditions at AEDC.

The Castor IIA is ready for incorporation into an operational system.

RECOMMENDATIONS

To enhance statistical evaluation and prediction of performance of the Castor IIA, additional static tests are recommended. These could be quality assurance tests as parts of future procurements. A repeat of simulated altitude testing on at least one motor is desirable because temperature and performance data were partially obscured in motors 5 and 22 by malfunction of the diffuser. One additional sea level test is desirable to provide further data for calculation of ratio of specific heats.

Improvement of propellant physical properties is desirable to reduce the probability of rejecting motors and to increase the inherent reliability of the design. Significant improvements in physical properties have been indicated through the use of a bimodal oxidizer blend of rounded ammonium perchlorate. Such a system has the further advantage of eliminating the necessity for grinding of oxidizer. Development of a propellant using blends of rounded ammonium perchlorate is recommended.

The Castor IIA provides an improvement in performance over the Castor I and should be considered for use wherever performance improvement is desirable.

TABLE I

TABULATION OF TX354-3 PFRT MOTOR PERFORMANCE VERSUS REQUIREMENTS OF NASA DEVELOPMENT SPECIFICATION P39-023

Parameter	P39-023	Motor 5	Motor 6	Motor 7	Motor 22	Average
Web Time, sec	37.0 ± 1.0	37.277	37.415	37.098	37.148	37.235
Total Time, sec	40 max.	39.237	39.184	38.774	39.278	39.118
Average pressure, psia	none	632	630	641	628	633
Maximum pressure, psia	none	714	710	711	711	712
Average thrust, lbs	none	61,680	61,000	61,600	61,340	61,400
Maxunum thrust, lbs	70,000	70,880	69,400	69,040	71,140	70,100
Total impulse, lb-sec	2,310,000 (min)	2,318,400	2,317,300	2,315,000	2,313,700	2,316,100
Specific impulse lb-sec/lb	278 min	282.6	282.2	281.9	282.1	282.2
Reference specific impulse[1], lb-sec/lb	none	254.7	253.6	253.6	253.2	254.0
Characteristic velocity, C^+, ft/sec	none	5190	5195	5244	5166	5199
Motor efficiency factor, Cm	none	0.9768	0.9719	0.9636	0.9790	0.9728
Propellant weight, lbs	none	8203.54	8212.35	8200.85	8205.96	8205.68

1. The reference specific impulse values for the PFRT motors were calculated for the following standard reference conditions:

Reference Conditions	Value
Average chamber pressure, psia	1000
Atmospheric pressure, psia	14.7
Nozzle expansion ratio, (Optimum)	9.833
Nozzle Divergence Half-Angle, Degrees	0
Temperature, °F	70
Motor Tail-Off Coefficient, C_{TO}	1.00

$$C_{TO} = \left(\frac{P_c}{\overline{F}} \frac{I_T}{pdt} \right)$$

TABLE II

MOTOR CASE FLEXURAL STIFFNESS

$G = 11.54 \times 10^6$

$E = 30 \times 10^6$

$\text{Area} = (R_o^2 - R_i^2)$

$I = \frac{}{4} (R_o^4 - R_i^4)$

$\frac{e}{g} = \frac{.284}{32.17\ (12)} = 7.35 \times 10^{-4}$

Sta.[1]	X[2]	R_o (in)	R_i (in)	A (in^2)	AG x 10^6	I in^4	$\frac{e}{g}$ I	EI x 10^9
1	1.606	10.750	9.000	108.582	1253.04	5335.76	3.922	160.07
2	2.606	11.143	10.256	59.630	688.13	3419.09	2.513	102.57
3	3.606	11.966	11.275	50.453	582.23	3409.47	2.506	102.28
4	4.606	12.673	12.128	42.464	490.03	3266.44	2.428	97.99
5	5.606	13.281	12.846	35.705	412.04	3047.47	2.240	91.42
6	6.606	13.801	13.453	29.796	343.85	2765.90	2.033	82.98
7	7.606	14.242	13.962	24.810	286.31	2467.14	1.813	74.01
8	8.606	14.610	14.383	20.676	238.60	2172.67	1.597	65.18
9	9.606	14.911	14.725	17.317	199.84	1901.30	1.397	57.04
10	10.606	15.147	14.992	14.676	169.36	1666.44	1.225	49.99
11	11.606	15.322	15.205	11.221	129.49	1307.09	.961	39.21
12	12.606	15.435	15.319	11.208	129.34	1325.04	.974	39.75
13	13.606	15.493	15.383	10.670	123.13	1271.52	.935	38.15
14	14.081	15.500	15.390	10.675	123.19	1273.25	.936	38.20
15	189.57	15.500	15.375	12.125	139.92	1444.77	1.062	43.34
16	190.92	15.500	15.200	28.934	333.90	3409.09	2.506	102.27
17	191.97	15.500	14.250	116.828	1348.20	12947.9	9.625	388.44

1. Station locations are shown on Figure 3.
2. "X" is the perpendicular distance measured from the aft missile attachment flange.

TABLE III

NOZZLE FLEXURAL STIFFNESS

$G = 11.54 \times 10^6$

$E = 30 \times 10^6$

$\frac{e}{g} = \frac{.284}{32.17\ (12)} = 7.3 \times 10^{-4}$

$\text{Area} = (R_o^2 - R_i^2)$

$I = \frac{}{4} (R_o^4 - R_i^4)$

Station [1]	"X"[2]	Area (in^2)	I (in^4)	$\frac{e}{g}$ I	AG x 10^6	EI x 10^9
1	2.09	31.354	5731.1	4.213	361.83	171.90
2	6.29	18.928	2869.9	2.109	218.43	86.10
3	16.53	18.843	1688.8	1.242	217.45	50.66
4	21.81	22.238	1431.2	1.052	256.63	42.94
5	28.85	32.640	1237.1	.909	376.67	37.11
6	32.35	68.050	2044.3	1.503	785.30	61.33
7	33.35	30.763	1015.4	.747	355.00	30.46

1. Station numbers designate sections taken perpendicular to the axis of revolution. Station locations are shown on Figure 5.
2. "X" is the perpendicular distance measured from the nozzle exit plane.

TABLE IV

"PYROGEN" PROPELLANT CHARACTERISTICS

Propellant Composition, Percent by Weight (TP-H8047)

Propellant Composition omitted to keep report unclassified

Ballistic Properties	
Characteristic Velocity, ft/sec	4865
Ratio of Specific Heats	1.22
Temperature Coefficient of Pressure, %/°F	0.090
Temperature Coefficient of Burning Rate, %/°F	0.085
Flame Temperature, Chamber, °F	2304
Flame Temperature, Nozzle, °F	1692
Autoignition Temperature, °F	350
Physical Properties (JANAF Specimen, Typical), 77°F	
Modulus, psi	**970**
Maximum Stress, psi	**196**
Strain at Maximum Stress, in/in	**0.238**
Specific Weight, #/in^3	**0.060**

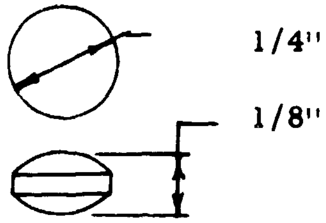
TABLE V.

CHARACTERISTICS OF BORON POTASSIUM NITRATE PELLETS

Composition	
Ingredients	Parts By Weight
Boron	23.7
Potassium Nitrate	70.7
Binder (Laminac)	5.6

Typical Configuration

Crown
Tablet (2D)



Properties

	B-KNO_3 (2D)
Physical Properties	
Weight, gm.	0.153
Surface Area, in.^{2}	0.160
Crush Strength (longitudinal), gm.	6500
Combustion Properties	
Heat of Explosion, cal./gm.	1600
Flame Temperature, °F	4080
Burning Rate, cm./sec.	1.03
Gas Volume, ml./gm.	120
Sensitivity	
Autoignition Temperature, °F	700
Detonation Rate, m./sec.	will not detonate
Electric Spark Sensitivity Classification	not sensitive
ICC Shipping Classification *	B

---

* Shipping classification by authority of Bureau of Explosives, Association of American Railroads, South Amboy, N. J. in a letter to Thiokol Chemical Corporation, dated 2 November 1959.

TABLE VI.

ELECTRIC INITIATOR CHARACTERISTICS
(CR-38682)

Physical Characteristics

Length in.	1.280
Diameter in.	1.000
Weight lb.	0.112
Threads (Installation)	3/4-10UNC-2A
Mating Connector	Bendix Pygmy PC06 8-4S
Gasket (Installation)	MS-35769-15
Torque (installation)	35 ± 5 ft/lbs
Auto-Ignition Temperature (Minimum)	400°F
Auto-Ignition Time	30 Minutes

Electrical Characteristics

Number of Circuits	2
Circuit Resistance	2.4 ± 0.10 OHMS
Insulation Resistance (minimum)	50 meghoms at 500 volts DC
Maximum Safe Continuity Test Current (per circuit)	0.005 Ampere
Maximum No-Fire Current (per circuit)	0.3 Ampere
Minimum All-Fire Current (per circuit)	1.0 Ampere
Minimum Recommended Firing Current (per circuit)	1.25 Ampere
Maximum Recommended Firing Current (per circuit)	8.0 Ampere
Electrostatic Sensitivity, No-Fire Pin to Case	15 KV (min), 0.005 MFD. Capacitor

Performance

Function Delay Time (Maximum at 1.25 amp. circuit)	0.020 secs.
Pressure Output (in 0.060 seconds maximum)	2000 ± 600 psi.

TABLE XIV

INSULATION EROSION IN TX-24 (TEST 1)

Erosion (mils/sec.) and Char (total) Versus Gas Velocity

Mach	TI-O700A	Char (in.)	TI-L700B	Char (in.)
0.02	Swelled	0.19	Swelled	0.15
0.03	Swelled	0.19	Swelled	0.19
0.03	Swelled	0.17	Swelled	0.18
0.05	Swelled	0.14	Swelled	0.13
0.06	Swelled	0.15	Swelled	0.12
0.08	Swelled	0.18	Swelled	0.17
0.08	1,4,1 avg. 2	----	Sw., 1,1 avg. 1	0.17
0.12	3,3 Sw. avg. 2	0.20	Sw., 2, avg. 1	0.11
0.17	5,2,1 avg. 3	0.20	3,7,4 avg. 5	0.11
0.23	Swelled	0.55*	Swelled	0.42*

* High Char Due to Back Heating of Graphite Throat.

At Mach 0.09 - 0.22 all measured erosion rates are shown, followed by a numerical average.

TP-H8038
Avg. Pressure: 473 psi
B-1926-8
T_B 29.2
1/17/64

TABLE XV

INSULATION EROSION IN TX-24 (Test 2)

Erosion (mils/sec.) and Char (total) Versus Gas Velocity

Mach	TI-O700A	Char (in.)	TI-L700B	Char (in.)
0.02	Swelled	*	Swelled	0.081
0.03	Swelled	*	4	0.060
0.04	1	*	4	0.070
0.06	4	*	4	0.140
0.07	4	*	3	0.061
0.08	7	*	7	0.071
0.09	10,5,5 Avg. 7	0.160	6,4,6 Avg. 5	0.080
0.12	7,9,4 Avg. 7	0.120	5,5,10 Avg. 7	0.060
0.17	5,8,11 Avg. 8	0.120	9,7,14 Avg. 10	0.050
0.21	4,3,0 Avg. 2	0.400**	2,9,9 Avg. 7	0.300**

* No Measurements Taken.

** High Char Due to Back Heating of Graphite Throat.

At Mach 0.09 - 0.21, all measured erosion rates are shown, followed by a numerical average.

TP-H7021
B-1931-4
Avg. Pressure: 639 psi
T_B 21.8 sec.
1/17/64

TABLE XVI

INSULATION EROSION IN TX-24 (Test 3)

Erosion (mils/sec.) and Char (total) Versus Gas Velocity

Mach	TI-O700A	Char (in.)	TI-L700B	Char (in.)
0.03	5	0.14	5	0.16
0.04	5	0.09	5	0.11
0.06	5	0.09	7	0.09
0.08	6	0.11	9	0.08
0.09	7	0.16	7	0.11
	FM-5067			
0.10	11,16,13 Avg. 12*	0.18**		
0.12	6,9,8 Avg. 8	0.14		
0.13	6,8,8 Avg. 8	0.14		
0.26	12,10,11 Avg. 11	0.17		
0.21				

---

* The "16-mil" erosion has been ignored for numerical average because material was poorly matched to adapter insulation at this location.

** The heavier char at the mismatched area has been ignored for the same reason.

TP-H7021
Avg. Pressure: 635 psi
T_B 22.59 sec.
1/13/64
B-1931-3

TABLE XVII

ADHESIVE STRENGTH OF TI-O700A INSULATION TO GRIT BLASTED STEEL

Storage Time (wks.)	Test Temp. (°F)	Adhesive Strength Average (psi)	Adhesive Strength Minimum (psi)	Failure
0	0	1168	1092	2 - I, I - B
0	77	975	711	4 - I
0	135	347	237	4 - B
1	0	1235	1041	4 - I
1	77	1505	1308	4 - B
1	135	505	406	4 - B
2	0	1240	1070	4 - I
2	77	1052	889	4 - I
2	135	416	381	4 - I
4	0	1190	1090	4 - I
4	77	1320	1190	4 - I
4	135	330	140	4 - B
8	0	1038	800	4 - I
8	77	996	800	4 - I
8	135	411	340	4 - B
12	0	1080	1025	3 - M
12	77	830	820	2 - TCM
12	135	445	340	3 - TCM

TABLE XVIII

ADHESIVE STRENGTH OF TL-H711B LINER TO TI-O700A INSULATION AT THREE TEMPERATURES THROUGH TWELVE WEEKS STORAGE TIME

Storage Time (wks.)	Test Temp. (°F)	ADHESIVE STRENGTH TL-H711B to Grit Blasted Steel Avg. psi	Min. psi	Failure	TL-H711B to TI-O700A Avg. psi	Min. psi	Failure
0	0	211	188	4 - B	205	172	4 - B
0	77	51	46	4 - B	45	30	4 - B
0	135	22	20	4 - L	23	23	4 - B
1	0	---	---	-----	---	---	-----
1	77	55	43	2 - L, 2 - B	31	28	4 - B
1	135	26	24	4 - L	16	13	4 - B
2	0	206	187	3 - B, 1 - M	183	160	4 - B
2	77	51	47	2 - B, 2 - L	33	29	4 - B
2	135	45	43	4 - M	20	18	4 - B
4	0	185	173	4 - B	146	141	3 - B
4	77	51	47	2 - L, 2 - B	36	32	4 - B
4	135	60	56	4 - L	25	20	4 - B
8	0	221	215	2 - B, 2 - L	176	150	4 - B
8	77	66	50	4 - L	48	35	4 - B
8	135	50	48	4 - L	23	22	4 - B
12	0	188	180	4 - TCL	161	148	1 - B, 3 - TCL
12	77	72	60	2 - L, 2 - TCL	45	35	2 - B, 2 - TCL
12	135	68	65	4 - L	26	20	3 - B, 1 - TCL

TABLE XIX

PEEL STRENGTH OF TL-H711B LINER TO TI-O700A AND GRIT BLASTED STEEL AT THREE TEMPERATURES THROUGH TWELVE WEEKS STORAGE TIME

PEEL STRENGTH

Storage Time (wks.)	Test Temp. (°F)	TL-H711B to TI-O700A				TL-H711B to Grit Blasted Steel			
		Max. pli	Avg. pli	Min. pli	Failure	Max. pli	Avg. pli	Min. pli	Failure
0	0	58	--	--	3 - T	63	--	--	3 - T
0	77	26	--	--	1 - B, 2 - T	28	27	24	3 - L, 1 - T
0	135	16	14	10	3 - B	30	25	25	2 - B, 1 - L
1	0	53	--	--	3 - T	58	--	--	3 - T
1	77	26	23	23	3 - B	20	--	--	3 - T
1	135	18	13	10	3 - B	44	33	30	2 - L, 1 - T
2	0	36	--	--	3 - T	47	--	--	3 - T
2	77	21	--	--	3 - T	65	51	50	1 - B, 1 - L, 1 - T
2	135	17	13	11	3 - B	48	44	42	3 - L
4	0	39	40	23	1 - B, 2 - T	53	--	--	3 - T
4	77	28	25	25	2 - B, 1 - T	52	45	40	3 - L
4	135	18	16	15	3 - B	50	42	40	3 - L
8	0	61	--	60	1 - B, 2 - T	48	--	--	3 - T
8	77	30	26	21	2 - B, 1 - T	26	--	--	3 - T
8	135	17	14	12	3 - B	39	--	--	3 - T
12	0	56	--	50	1 - B, 1 - T	45	--	--	3 - T
12	77	27	23	22	2 - B, 1 - T	33	--	--	3 - T
12	135	20	15	15	3 - B	47	--	--	3 - T

TABLE XX

TENSILE STRENGTH OF TL-H711B LINER AND TI-O700A INSULATION

TENSILE STRENGTH

Storage Time (wks.)	Test Temp. (°F)	TL-H711B		TI-O700A	
		Ult. Stress psi	Ult. Strain %	Ult. Stress psi	Ult. Strain %
0	40	196	2181	2839	5
0	77	113	2013	1458	12
0	100	147	1973	1186	9
1	0	166	1688	2780	5
1	77	175	1727	2552	10
1	135	207	1587	1700	11
2	0	120	1890	1892	4
2	77	164	1800	1385	9
2	135	235	1650	1460	10
4	0	165	1752	3011	6
4	77	182	1718	1586	6
4	135	239	1627	2405	8
8	0	*		2766	5
8	77			1292	7
8	135			1812	6
12	0			2050	2
12	77			1318	4
12	135			1973	3

* Too soft to test at the 8 and 12 week periods.

TABLE XXI. LOT NUMBERS OF RAW MATERIALS USED FOR INSULATION OF TX-354 MOTORS.

	Motor No.	1	2	3	4	5	8	9	10	11	12	13	14	15
Adiprene-L	Lot No.	96	96	96	96	96/19	96	96	96	96	96	96	96	96
	Drum No.	12, 3	12, 1	12, 1	12	12/12	12, 1	1, 2, 12	12	12	12	12	12	12
ERL	Lot No.	60	60	60	68	68	63	68	68	68	68	68	68	68
	Drum No.	2	2	2, 3	2	2	3	2	2	7, 2	2, 7	2	2	2
RTA	Lot No.	NLNA-2	2427	2427	2427	2499/2427	2427	2427	2427	2427	2427	2427	2427	2427
	Drum No.	1	1	1	3, 1	2 2	1	1	3	2	2	2	2	2
RTH	Lot No.	NLNA-3	2429	2429	2429	2429	2429	2429	2429	2429	2429	2429	2429	2429
	Drum No.	1, 8, 40	1	1, 2	4, 3	7	2, 3	3	4	4, 5	5, 4	5, 6	6	6, 7
MOCA	Lot No.	0470	2422	2422	2422	2422/2518	2422	2422	2422	2422	2422	2422	2422	2422
	Drum No.	1, 10	1	1	1	1 2	1	1	1	1	1	1	1	1
Carbon	Lot No.	2336	2336	2336	2406	2384	2336	2336	2406	2384	2384	2384	2384	2384
	Drum No.	31, 27, 37	30	3	31, 6	12	20	20, 8	34	1, 7, 12	1, 12, 7	1, 12	1, 12	2
Molacco	Lot No.	2218	2218	2218	2218	2510	2218	2218	2218	2510	2510	2510	2510	2510
	Drum No.	1, 9, 7, 8	9	9	9	2, 7	9	9	9	1, 4 7, 2	2, 1 4, 7	1, 2	2	2
Milled Glass	Lot No.	NLNA-1	2431	2431	2431	2496	2431	2431	2431	2431	2431	2431/2496	2431/2496/2429	2496
	Drum No.	1, 2	1, 2	2, 1	1, 2	4	2, 4	4	8	11, 12	12, 11	12 1	12 1	1
Dibasic Ammonium Phosphate	Lot No.	1994	1944	1944	1944	1944	1944	1944	1944	1944	1944	1944	1944	1944
	Drum No.	1, 22, 2	22	22	7	7	22	22	5	5, 7	5, 7	7	7	7

TABLE XXII. ULTIMATE STRESS AND ELONGATION OF TI-O700A AS FUNCTIONS OF LOADING RATES

Loading Rate	Elongation at Failure (%)	Cross-Section	Stress At Failure	Remarks
.2"/min.	9.5	0.072 in.^{2}	1556	
	10.3		1270	
	6.5	0.0595	1765	air bubble
2.0"/min.	12.5	0.0592	2560	
	16.0	0.0729	2050	
10.0"/min.	11.0	0.0429	2410	
	14.0	0.0832	3070	
	12.0	0.0672	3160	
	10.0	0.0558	2150	air bubble
20.0"/min.	10.0	0.0646	3870	
	10.0	0.0732	3620	
	8.0	0.0731	2310	air bubble
	8.6	0.0567	3000	

TABLE XXIII. RAW MATERIALS, % BY WEIGHT, FOR TI-O700A INSULATION USED IN TX-354 MOTORS.

Mtr. No.	Adiprene L	ERL	RTA	RTH	MOCA	GLASS	Dibasic Ammonium Phosphate	Carbon	Molacco	Date* Insulated	Date Reworked
1	14.09	20.16	0.40	12.92	2.42	20.00	7.00	5.75	17.25	5 Feb	6 Feb
2	14.10	20.17	0.40	12.92	2.42	20.00	7.00	5.75	17.25	18 Mar	19 Mar
3	14.78	21.12	0.42	13.52	2.54	19.03	6.67	5.48	16.42	6 April	8 April
8	14.78	21.12	0.42	13.52	2.54	19.03	6.67	5.48	16.42	28 April	30 April
9	14.11	20.16	0.40	12.91	2.42	20.00	7.00	5.73	17.25	6 May	14 May
4	14.11	20.16	0.40	12.91	2.42	20.00	7.00	5.73	17.25	4 June	4 June
10	14.11	20.16	0.40	12.91	2.42	20.00	7.00	5.73	17.25	26 June	30 June
11	14.11	20.16	0.40	12.91	2.42	20.00	7.00	5.73	17.25	13 July	15 July
12	14.11	20.16	0.40	12.91	2.42	20.00	7.00	5.73	17.25	14 July	15 July
13	14.11	20.16	0.40	12.91	2.42	20.00	7.00	5.73	17.25	28 July	29 July
14	14.11	20.16	0.40	12.91	2.42	20.00	7.00	5.73	17.25	29 July	29 July
15	14.11	20.16	0.40	12.91	2.42	20.00	7.00	5.73	17.25	11 Aug	11 Aug
5	14.11	20.16	0.40	12.91	2.42	20.00	7.00	5.73	17.25	13 Aug	13 Aug

* All dates shown are for the year 1964.

TABLE XXIV. DATES INSULATION MIXES WEIGHED, MIXED, PLACED IN CURE

Motor Number	Insulation And Place	Mix No. Employed	Date* Weighed	Mixing Completed		Insulation In Cure	
				Date	Hours	Date	Hours
		13723	4 Feb	4 Feb	2015	5 Feb	1515
1	Fwd	13724	4 Feb	5 Feb	0130	5 Feb	1515
	Fwd Slot	13729	5 Feb	5 Feb	0705	5 Feb	1515
	Aft Slot	13726	4 Feb	5 Feb	1100	5 Feb	1515
	Aft	13725	4 Feb	5 Feb	1350	5 Feb	1515
	Patch	13730	5 Feb	6 Feb	0920	No Data	
2	Fwd	13872	16 Mar	16 Mar	0935	18 Mar	1500
	Fwd Slot	13873	16 Mar	16 Mar	1347	18 Mar	1500
	Aft Slot	13883	18 Mar	18 Mar	0845	18 Mar	1500
	Aft	13875	16 Mar	17 Mar	1348	18 Mar	1500
	Patch	13876	16 Mar	19 Mar	0917	19 Mar	1545
3	Fwd	13934	6 April	6 April	1140	6 April	1600
	Fwd Slot	13944	6 April	6 April	1348	6 April	1600
	Aft Slot	13945	6 April	7 April	0950	7 April	1500
	Aft	13946	6 April	7 April	1310	7 April	1500
	Patch	13950	7 April	8 April	1300	No Data	
4	Fwd	14114	3 June	3 June	0305	4 June	0030
	Fwd Slot	14115	3 June	3 June	0931	4 June	0030
	Aft Slot	14116	3 June	3 June	2130	4 June	0030
	Aft	14117	3 June	3 June	2308	4 June	0030
	Patch	14121	3 June	4 June	0955	4 June	1530
9	Fwd	14036	5 May	6 May	1120	6 May	2315
	Fwd Slot	14037	5 May	6 May	1340	6 May	2315
	Aft Slot	14039	6 May	6 May	1908	6 May	2315
	Aft	14040	6 May	6 May	2206	6 May	2315
	Patch	14042	6 May	14 May	1025	14 May	1500
	Patch	14043	6 May	14 May	1315	14 May	1500
8	Fwd	14013	27 April	28 April	1040	28 April	1545
	Fwd Slot	14014	28 April	28 April	1331	28 April	1545
	Aft Slot	14015	28 April	29 April	0933	29 April	1500
	Aft	14016	28 April	29 April	1325	29 April	1500
	Patch	14018	28 April	30 April	1030	30 April	1600
10	Fwd	14188	25 June	25 June	1018	26 June	0700
	Fwd Slot	14189	25 June	25 June	2345	26 June	0700
	Aft Slot	14190	25 June	25 June	0340	26 June	0700
	Aft	14191	25 June	26 June	0615	26 June	0700
	[illegible]	14192	25 June	26 June	1410	26 June	1800
	Patch	14193	25 June	26 June	1747	26 June	1800
		14205	30 June	30 June	2140	30 June	2300

* All dates shown are for the year 1964

TABLE XXIV.(Continued)

Motor Number	Insulation Mix No. And Place Employed		Date* Weighed	Mixing Completed		Insulation In Cure	
				Date	Hours	Date	Hours
11	Fwd	14237	13 July	13 July	1935	14 July	0700
	Fwd Slot	14238	13 July	13 July	2205	14 July	0700
	Aft Slot	14241	13 July	14 July	0330	14 July	0700
	Aft	14240	13 July	14 July	0545	14 July	0700
		14248	15 July	15 July	1730	15 July	2000
	Patch	14249	15 July	15 July		15 July	2000
12	Fwd	14232	10 July	14 July	1405	15 July	0300
	Fwd Slot	14242	14 July	14 July	1807	15 July	0300
	Aft Slot	14243	14 July	14 July	2212	15 July	0300
	Aft	14244	14 July	15 July	0110	15 July	0300
	Patch	14248	15 July	15 July	1730	16 July	0100
13	Fwd	14279	27 July	28 July	0733	28 July	1700
	Fwd Slot	14280	27 July	28 July	0920	28 July	1700
	Aft Slot	14282	28 July	28 July	1241	28 July	1700
	Aft	14283	28 July	28 July	1437	28 July	1700
		14291	29 July	29 July	1352	29 July	1500
	Patch	14292	29 July	29 July	1745	29 July	1500
14	Fwd	14286	28 July	28 July	2215	29 July	0800
	Fwd Slot	14287	28 July	29 July	0205	29 July	0800
	Aft Slot	14286	28 July	29 July	0440	29 July	0800
	Aft	14289	28 July	29 July	0615	29 July	0800
	Patch	14292	29 July	29 July	1745	29 July	2100
15	Fwd	14308	6 Aug	10 Aug	2252	11 Aug	1500
	Fwd Slot	14307	6 Aug	10 Aug	0259	11 Aug	1500
	Aft Slot	14309	6 Aug	10 Aug	0624	11 Aug	1500
	Aft	14310	6 Aug	11 Aug	1324	11 Aug	1500
	Patch	14311	6 Aug	11 Aug	2012	11 Aug	2400

* All dates shown are for the year 1964

TABLE XXV. RETAINED INSULATION WEIGHTS FOR TX-354 MOTORS

Motor No.	1	2	3	4	8	9	10	11	12	13	14	15	5
Head	20.4	15.6	16.1	14.1	12.3	12.5	11.0	14.0	13.0	12.5	14.6	14.5	15.15
Forward Slot	40.8	36.5	32.0	36.0	40.0	34.3	35.9	33.2	34.3	33.5	38.0	34.5	38.10
Aft Slot	45.8	33.1	33.9	33.2	34.3	32.8	33.4	36.0	35.9	35.7	35.7	32.5	37.40
Aft	25.8	26.4	22.7	23.1	25.7	26.3	27.0	26.1	24.7	22.4	22.3	22.9	24.70
Patching*	2.8	10.3	14.2	14.3	14.0	12.0	9.3	5.1	8.6	5.3	5.8	6.0	2.35**

---

* This patching material is added as required throughout the motor. The values for Motors 10 through 15 are more typical of recent operations, since tighter dimensional controls were established beginning with Motor 10.

** Records indicate patching operations had not been completed.

TABLE XXVI

PEEL STRENGTH OF TL-H711B LINER TO TP-H7021 PROPELLANT AT THREE TEMPERATURES THROUGH TWELVE WEEKS STORAGE TIME

PEEL STRENGTH

Storage Time (wks.)	Test Temp. (°F)	Max. pli	Avg. pli	Min. pli	Failure
0	0	47	25	18	3 - Prop.
0	77	33	11	9	3 - Prop.
0	135	28	16	9	3 - Prop.
1	0	49	42	25	3 - Prop.
1	77	31	19	7	3 - Prop.
1	135	25	17	12	3 - Prop.
2	0	57	46	32	3 - Prop.
2	77	27	18	15	3 - Prop.
2	135	21	15	13	3 - Prop.
4	0	25	17	10	3 - Prop.
4	77	21	14	8	3 - Prop.
4	135	17	10	7	3 - Prop.
8	0	35	21	18	3 - Prop.
8	77	17	8	5	3 - Prop.
8	135	18	12	5	3 - Prop.
12	0	36	23	16	3 - Prop.
12	77	10.6	12.6	10	1 - B, 2 - Prop.
12	135	16	8.6	5	3 - Prop.

TABLE XXVII. DATA FROM HYDROTEST OF TX-362 PYROGEN CASES

Case Serial Number	Maximum Pressure (psi)	Comments
5	6,800	At maximum pressure, case began to "weep" 1 inch from the nozzle end.
6	7,300	At maximum pressure, case began to "weep" 1 inch from the nozzle end.
7	8,300	Case extruded out of test fixture.
8	3,150	First hydrodynamic test of this case. Pressure increased to maximum value in about 120 milliseconds. No case failure.
	3,100	Second hydrodynamic test of this case. Pressure increased to maximum value in 100 milliseconds. No case failure.
10	3,050	Hydrodynamic test. Pressure increase to maximum value in 60 milliseconds. No case failure.

TABLE XXVIII

SUMMARY OF PYROGEN UNITS LOADED

Charge No.	Thiokol S/N	Case S/N
Mix J-2684		
1	12	13
2	13	15
3	14	16
4	15	17
5	16	18
6	17	21
7	18	22
8	19	23
9	20	24
10	21	25
11	22	26
Mix J-2677		
15	1	3
16	2	4
17	3	2
18	4	1
Mix J-2690		
1	23	27
2	24	35
3	25	28
4	26	31
5	27	38
6	28	39
7	29	34
8	30	30
9	31	29
10	32	37
11	33	32
12	34	36
13	35	33
14	36	40
Mix J-2700		
1	37	41
2	38	43
3	39	44
4	40	45
5	41	46
6	42	47
7	43	48
8	44	49
9	45	52
10	46	53
11	47	54
Mix R-634		
1	5	15
2	6	17
3	7	13
4	8	16
5	9	18
6	10	21
7	11	22

TABLE XXIX

PYROGEN UNIT TESTS

Pyrogen Units Fired Outside

	Order of Test	Mix & Charge	S/N	t_1 0 to P_{init} (msec)	t_2 P_{init} - P_{max} (msec)	t_b P_{init} - WBO (msec)	P_{max} (psia)	P_{avg} (psia)	Temp. (°F)	Pellets
	1[a]	J-2677-17*	3	3	8	281	1655	1085	70 (Bulged Retainer)	20 gm 2-D
	2	J-2677-16*	2	4	8	280	1500	1061	70	15 gm
Batch Check	4	J-2684- 5*	18	4	10	262	1560	1075	70 (First with new Retainer)	17 gm 2-D
Qualification Rounds	5	J-2684- 1*	12	8	10	268	1400	1004	20	17 gm 2-D
	6	J-2684- 2*	13	6	10	253	1510	1083	70	17 gm 2-D
	7	J-2684- 6*	17	6	10	262	1475	1047	20	17 gm 2-D
	8	J-2684- 7*	18	6	10	259	1540	1067	120	17 gm 2-D
	11	J-2690-14*	36	8	8	256	1785	1199	120	17 gm 2-D
	9	J-2690- 1*	23	6	8	290	1565	1086	20	17 gm 2-D
	10	J-2690- 4*	26	8	6	277	1625	1116	70	17 gm 2-D
	12	J-2690- 5*	27	5	11	277	1575	1125	70	17 gm 2-D
	13	J-2690-12*	34	4	11	258	1760	1240	120	
	14	J-2690-13*	35	6	17	270	1585	1093	20 (at 250,000 feet)	17 gm 2-D
Check		J-2700- 3**	39	5	15	275	1455	1069	70	17 gm 2-D
Check		J-2700- 6**	42	4	14	271	1585	1138	120	17 gm 2-D
	Average (Excluding J-2677)			5.8	10.8	267.5	1570.8	1103.2		

* 2 M125 ** 1 M125's

TX-354 Motor Tests

Motor	Mix & Charge	S/N	ti d	td - 50%	ti - 10%	ti - 70%	ti - 90%	P_{max} During Ignition (psig)	P_{avg} (psig)	Temperature (°F)
1	J-2677-15[b]	1	19	120	85	148	194	693	590	75
3	J-2684-10	21	10	178	140	190	222	644	582	75 0.150 mmHg
8	J-2684- 4	15	15	148	92	195	330	828	607	74
9	J-2690- 3	25	17	240	89	210	361	1368		74
11	J-2684- 9	20	9	199	158	192	215	700	621	77
12	J-2684- 8	19	8	106	79	126	148	527		76
4	J-2690- 9	31	18		70	110	131	752	666	75
7	J-2700-10	46	170		185		237	495	609	20 .240 mmHg
6	J-2700- 8	44	8		67	108	130	530	649	110
5	J-2700- 5	41	13		82	124	153	482		75 23.1 mmHg
22	J-2700- 2	38	7		87	131	157	495		80 9.1 mmHg

---

a. Decreased nozzle to 1.140 from 1.168 after Motor Test No. 1 to increase weight flow. The retainer was also changed at this time after pellet charge tests.

b. 17 gm 2-D & 2 M 125's

TABLE XXX
PHYSICAL PROPERTIES OF TENSILE SPECIMENS MACHINED FROM HYDROBURST CASE

	Strength, Ksi		% Elongation
	Ultimate	0.2% Yield	in 2 inches
Forward Cylinder Longitudinal			
1	160.8	152.0	7.0
2	158.3	150.4	7.0
3	159.9	151.8	7.0
Avg.	159.7	151.4	7.0
Traverse			
1	156.6	149.6	9.5
2	158.5	151.5	10.5
3	158.8	150.9	10.5
Avg.	157.9	150.7	10.0
Center Cylinder Longitudinal			
1	158.6	151.6	9.0
2	157.1	149.9	7.0
3	155.4	148.6	7.5
Avg.	157.3	150.0	7.8
Girth Weld			
1	164.6	156.6	4.0
2	156.4	149.4	4.0
3	160.2	152.2	5.5
Avg.	160.4	152.7	4.5

TABLE XXXI. SUMMARY OF TX354 MOTORS LOADED AND DISPOSITION

MOTOR NO.	AGENCY	PROPELLANT	LOAD DATE	TEST DATE	REMARKS
1	NASA	H 7021	14 FEB 64	12 MAR 64	77° O.K.
2	"	H 7021	25 MAR 64	—	CRACKED SECOND 20° CYCLE
3	"	H 7021	15 APR 64	7 JULY 64	77° O.K. EVACUATED CHAMBER
4	"	H 7025	17 JUN 64	5 DEC 64	77° O.K. 2 CYCLES 20° TO 110° 1500 MI. TEST
5	"	H 7025	8 JAN 65	26 APR. 65	77° O.K. SIMULATED ALT. @ AEDC
6	"	H 7025	17 DEC 64	1 MARCH 65	110° O.K. 2 CYCLES 20° TO 110°
7	"	H 7025	17 DEC 64	31 JAN 64	20° O.K. EVACUATED CHAMBER
8	AFBSD	H 7021	7 MAY 64	16 JULY 64	77° O.K. HIGH INITIAL PRESSURE
9	"	H 7025	7 JULY 64	14 AUG 64	77° PRESSURE BURST @ 0.380 SEC.
10	"	H 7025	7 JULY 64	—	SHIPPED GREEN RIVER - RETURNED
11	"	H 7025	24 JULY 64	24 SEP 64	77° O.K.
12	"	H 7025	24 JULY 64	12 OCT 64	77° BURN THRU 7 SEC.
13					
14					
15					
16					
17					
18					
19					
20					
21					
22	NASA	H 7025	8 JAN 65	30 APR 65	77° O.K. SIMULATED ALT. @ AEDC

TABLE XXXII

PROPELLANT MIX SUMMARY

Motor	Propellant	Mix No.	Batch Size	Stoich. Polymer/ Curing Agent	Oxidizer Percentage		
					Sp. Coarse	Unground	Ground
1	TP-H7021	B-2014	3200	1/.915	50	25	25
		B-2007	4600				
		B-2008	4100				
2	TP-H7021	B-2054	3200	1/.915	50	25	25
		B-2055	4600				
		B-2056	4100				
3	TP-H7021	B-2083	3200	1/.915	50	25	25
		B-2084	4600				
		B-2085	4100				
4	TP-H7025	B-2144	3200	1/.83	60	15	25
		B-2145	4600				
		B-2146	3700				
5	TP-H7025	B-2230	4000	1/.84	60	20	20
		B-2231	4600				
		B-2232	4600				
		B-2303	4000				
6	TP-H7025	B-2287	4000	1/.85	60	20	20
		B-2288	4600				
		B-2293	4600				
		B-2295	4000				
7	TP-H7025	B-2287	4000	1/.85	60	20	20
		B-2293	4600				
		B-2294	4600				
		B-2295	4000				
8	TP-H7021	B-2107	3200	1/.915	46	27	27
		B-2108	4600				
		B-2109	4100				
9	TP-H7025	B-2114	4600	1/.83	60	15	25
		B-2115	4600				
		B-2116	4600				
		B-2175	4600				
10	TP-H7025	B-2114	4600	1/.83	60	15	25
		B-2116	4600				
		B-2174	4600				
		B-2175	4600				

TABLE XXXII (Cont'd)

Motor	Propellant	Mix No.	Batch Size	Stoich. Polymer/ Curing Agent	Oxidizer Percentage		
					Sp. Coarse	Unground	Ground
11	TP-H7025	B-2193	4000	1/.833	60	20	20
		B-2194	4600				
		B-2195	4600				
		B-2197	4600				
12	TP-H7025	B-2193	4000	1/.833	60	20	20
		B-2195	4600				
		B-2196	4600				
		B-2197	4600				
22	TP-H7025	B-2230	4000	1/.84	60	20	20
		B-2232	4600				
		B-2202	4600				
		B-2203	4000				

TABLE XXXIII

STATIC PRESSURE TEST SUMMARY

Test No.	E.O. CR 30563-C S/N	Weight, lbs	Thickness, in.	Burst Pressure, psig	Remarks
1	001	8.88	1.00	57	
2	002	9.05	0.70	29	
3	004	9.04	0.80	25	Note 1
4	004	9.11	0.80	Unknown	Note 2
5	004	8.93	0.80	13	Note 3
6	004	8.98	0.80	8	Note 4
7	005	9.11	0.80	47	
8	006	9.05	0.771	41	Note 5
9	006	8.75	0.774	40	
10	006	8.86	0.774	39	
11	006	9.09	0.767	44	
12	006	8.90	0.770	45	

Note 1. Failure appeared to occur around closure through nozzle insulation, which had begun to break down from repeated testing.

Note 2. Ice in pressure line blocked gage and caused absence of pressure reading.

Note 3. Scotchcast bonding material used. Failure in bond of Scotchcast to nozzle insulation.

Note 4. Failure in bond of RTV 88 due to use of wrong primer on nozzle body and closure. This was first test in series with closure bonded directly to metal shell due to loss of nozzle insulation.

Note 5. E.O. CR 30563-C S/N006 represents a design identical to Drawing R-42653. Tests 8 through 12, therefore, represent qualification tests of the final design.

TABLE XXXIV

DYNAMIC TEST SUMMARY - CLOSURE R 42653

Motor No.	Closure No.	Closure Weight, lbs	Thickness, in.	Burst Pressure, psia	Remarks
22	127	9.04	0.756	68.2	Note 1
5	128	8.94	0.772	44.1	Note 1
6	119	9.05	0.795	Unknown	Notes 2 and 3

Note 1. Time to closure rupture was 0.018 second on Motor 5 and 0.017 second on Motor 22 as indicated by breakwires.

Note 2. Motor head cap pressure registered 5 psig on a 1,000 psi gage at time of closure failure. No transducer was included in the closure to measure pressure acting on the closure.

Note 3. Closure in Motor 6 was an interim design per E.O. CR 30563-C S/N004 (Figure 122).

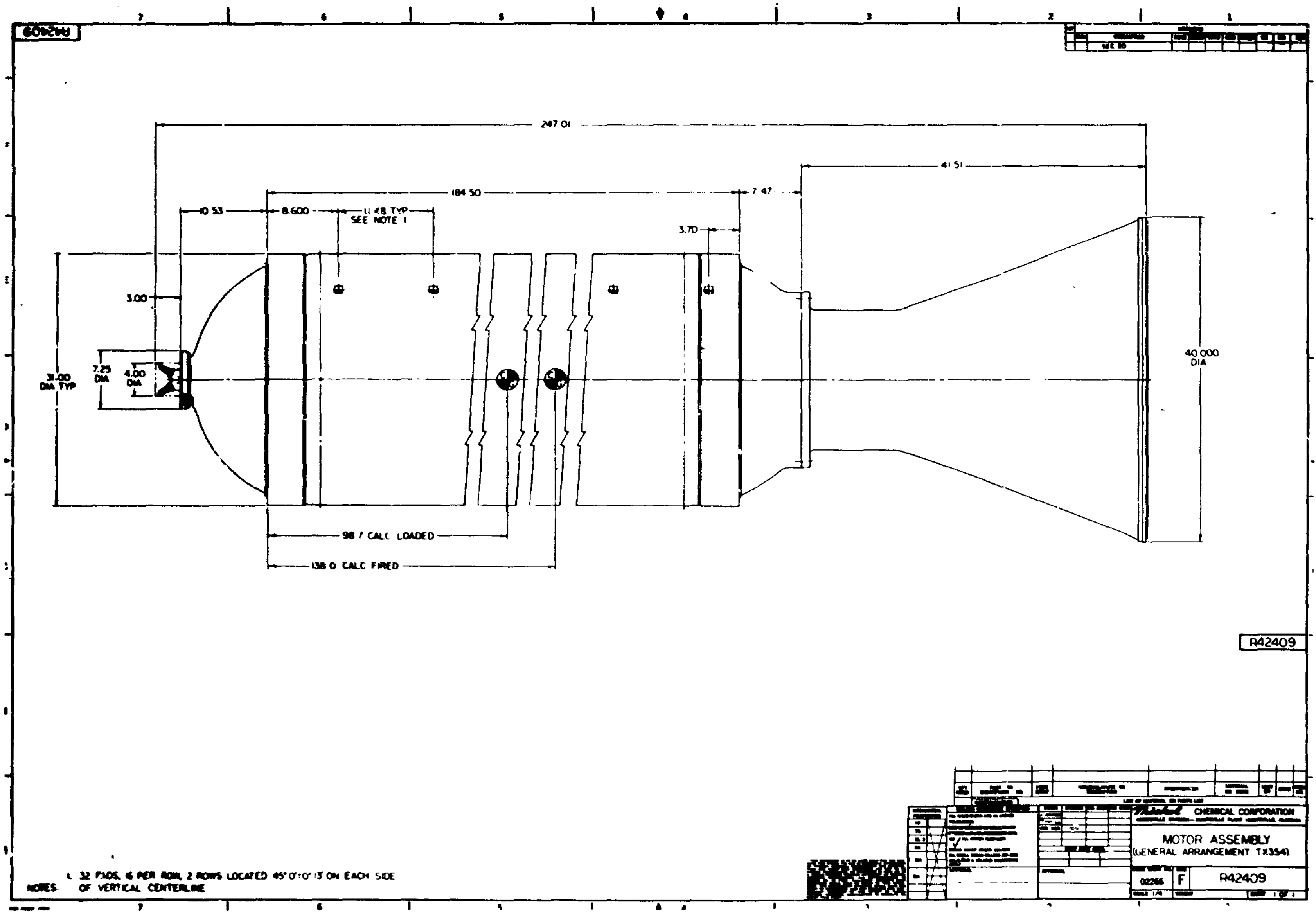


Figure 1. TX354 Motor Assembly.

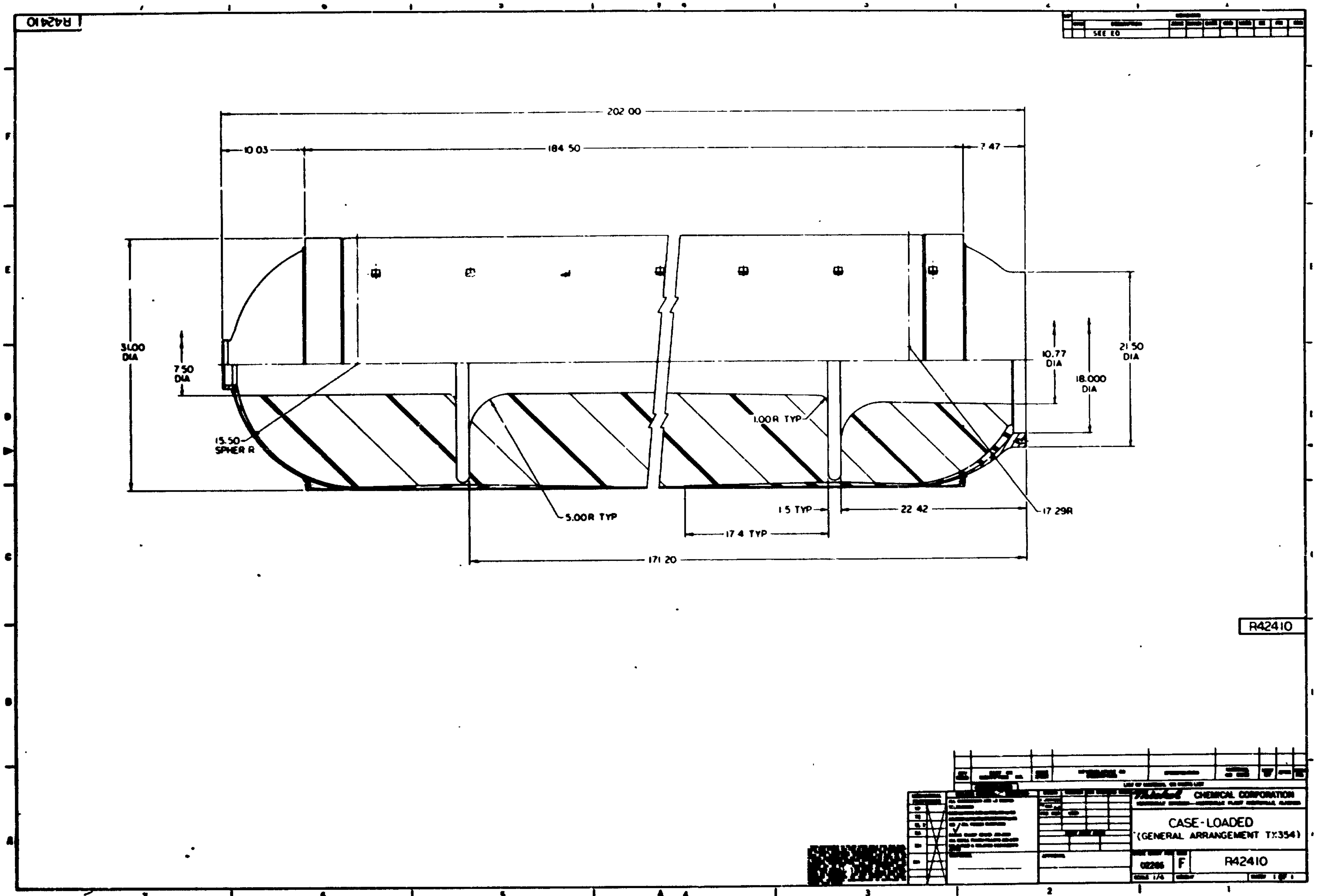


Figure 2. TX354 Loaded Case Configuration.

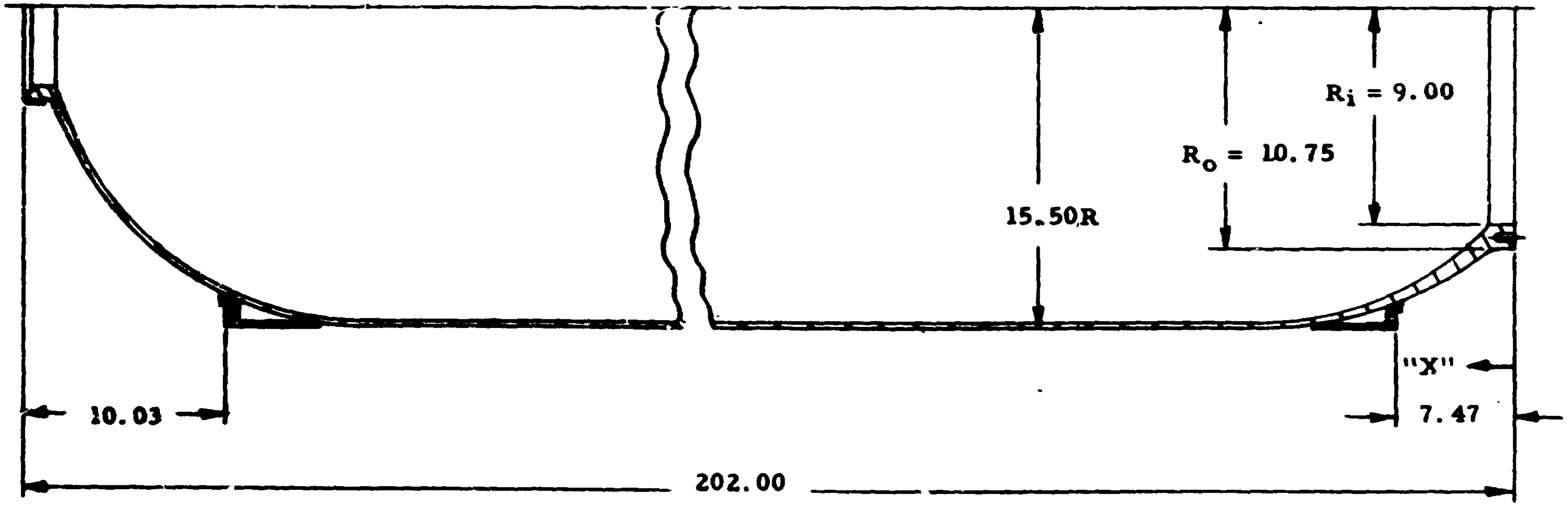


Figure 3. Station Locations for Motor Case Flexural Stiffness Determinations.

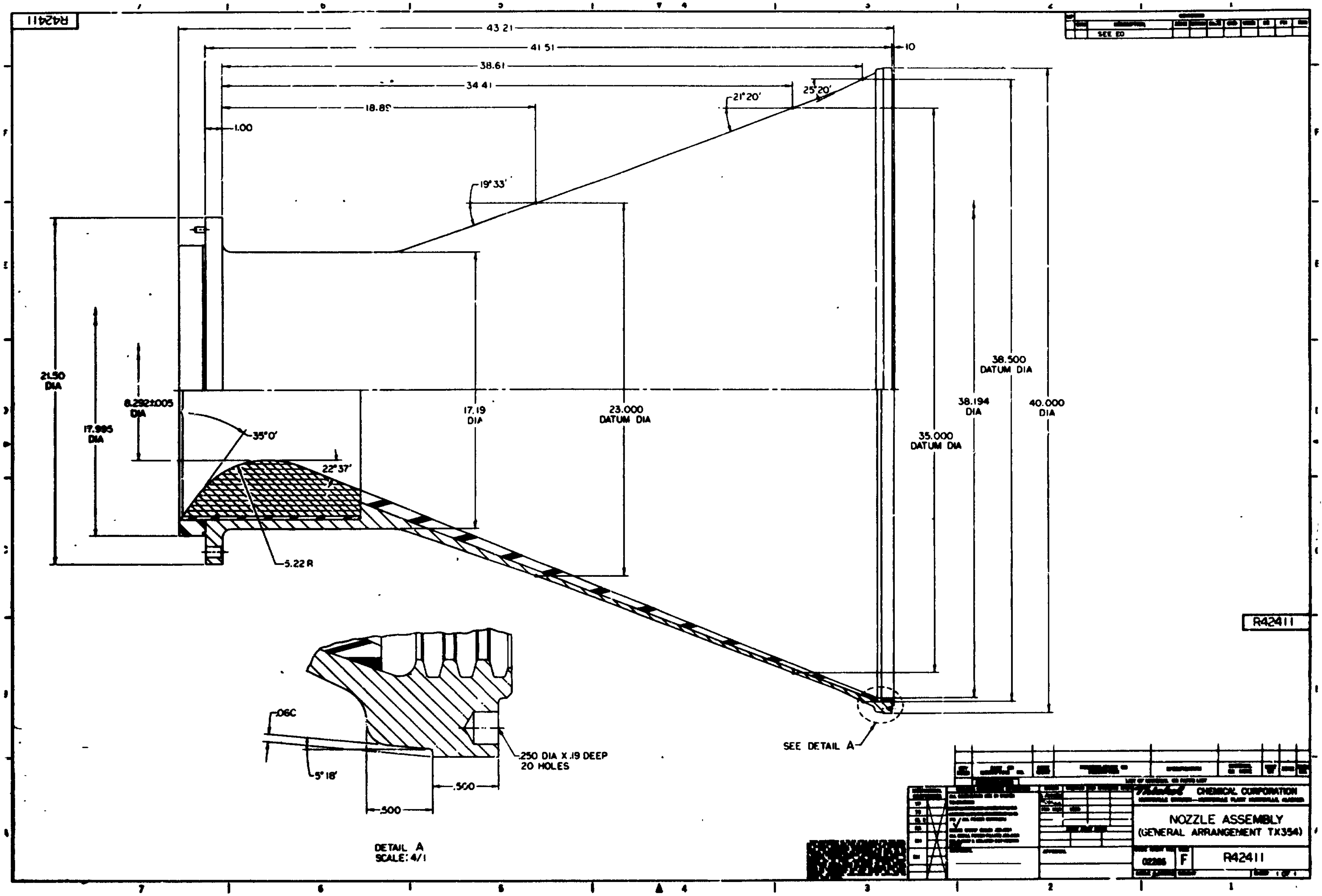


Figure 4. TX354 Nozzle Assembly.

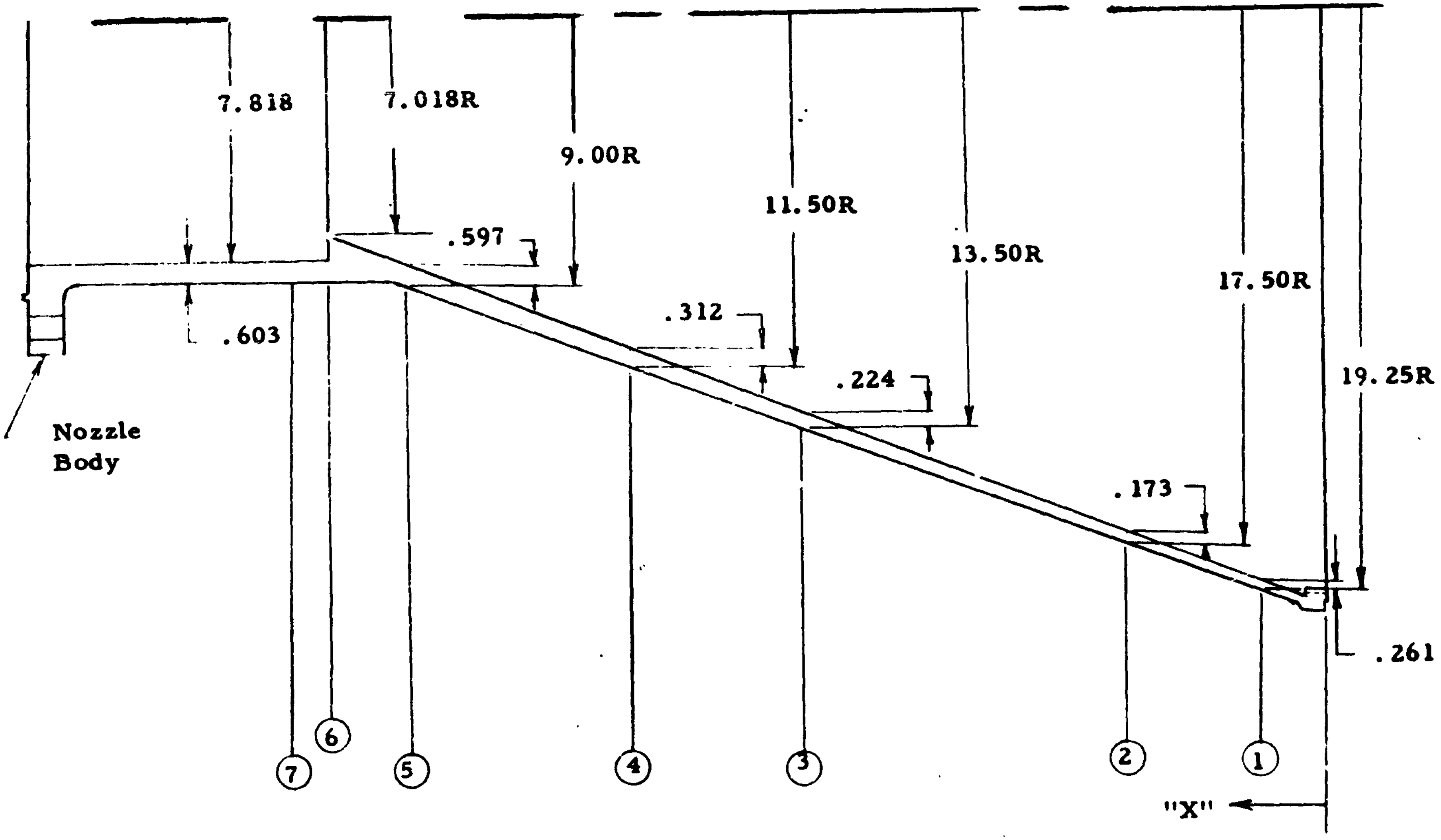


Figure 5. Station Locations for Nozzle Flexural Stiffness Determinations.

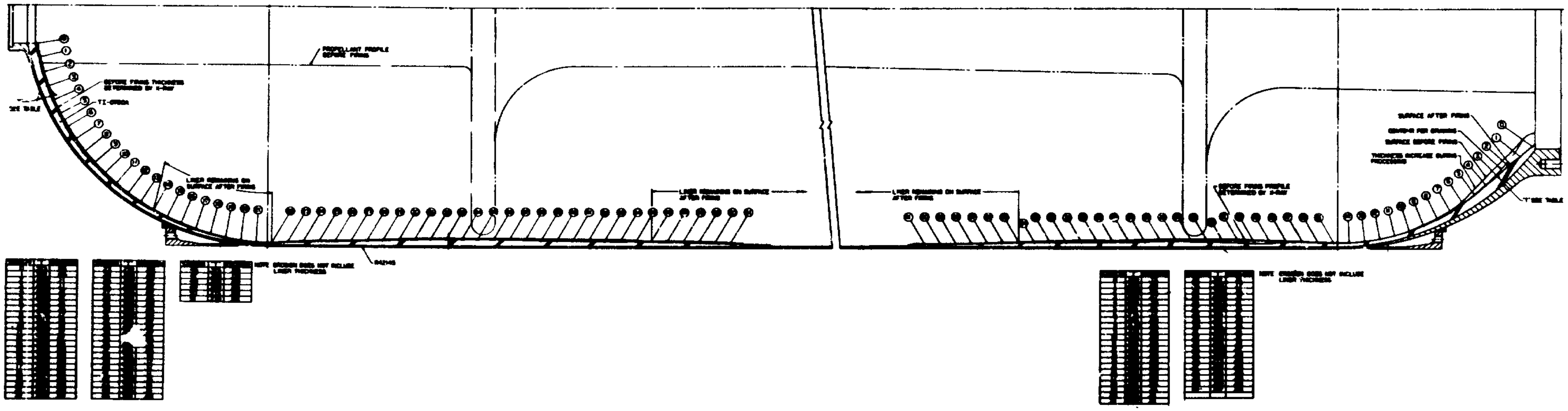


Figure 6. Erosion Profile of Motor Case Insulation from TX354 Motor 5.

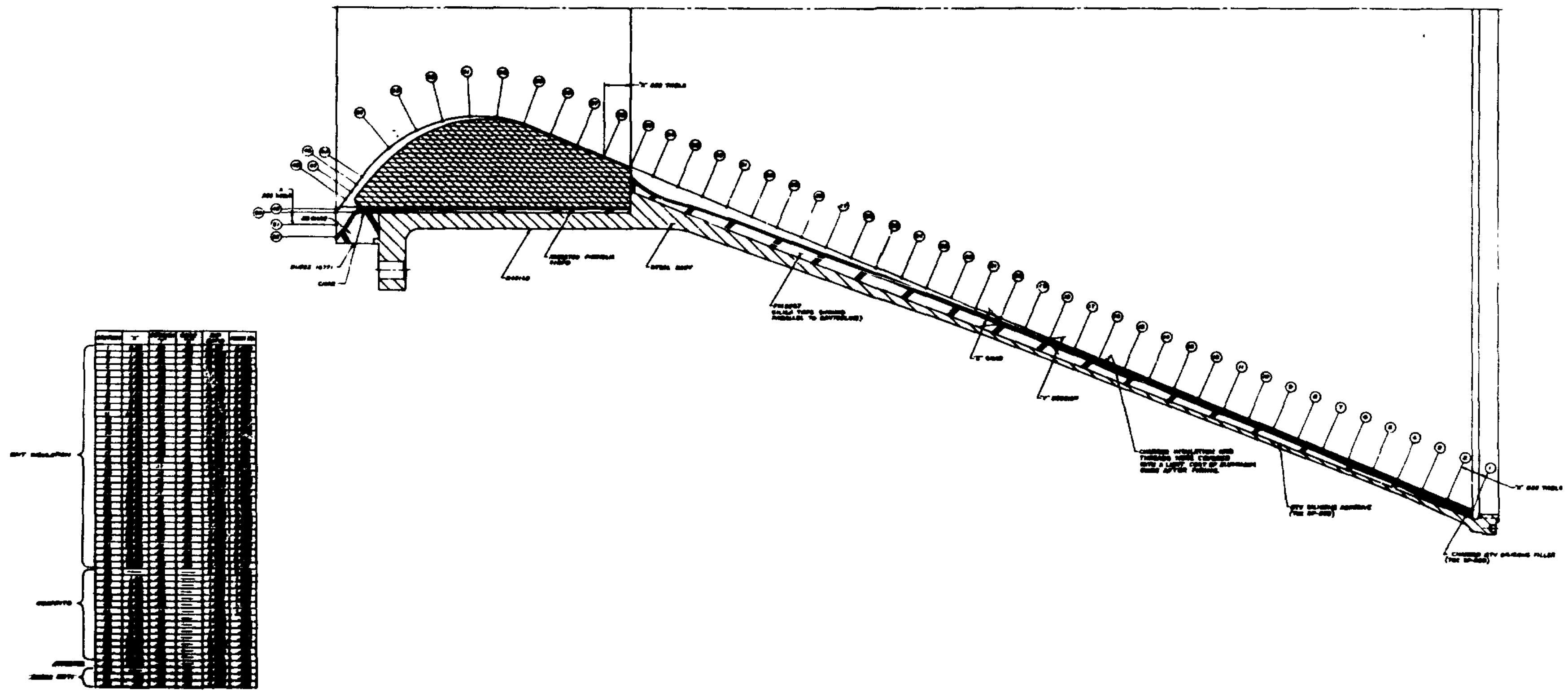


Figure 6A. Erosion Profile of Nozzle Assembly Used on TX354 Motor 5.

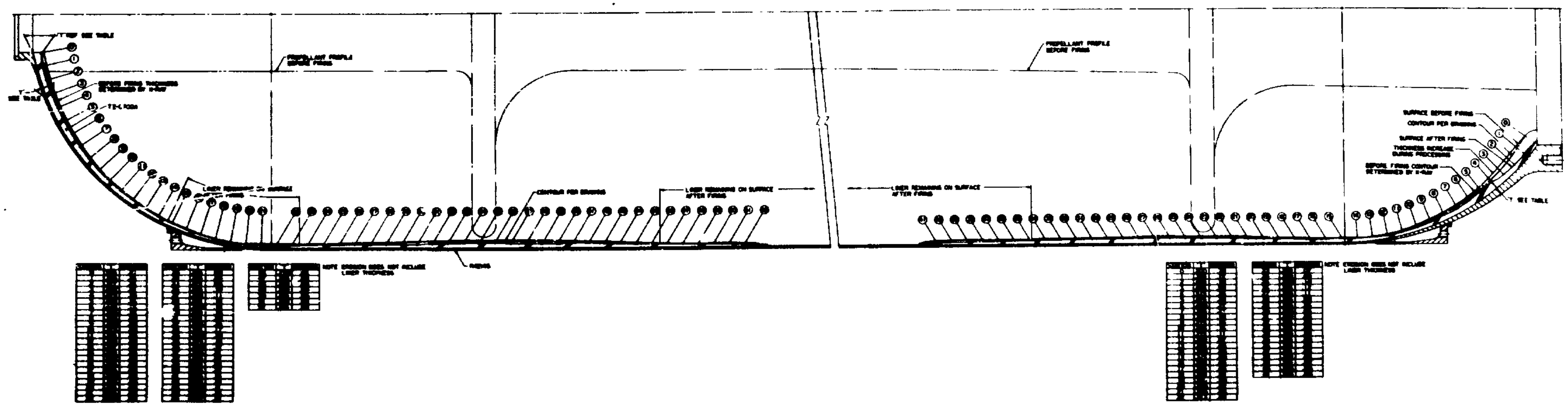


Figure 7. Erosion Profile of Motor Case Insulation from TX354 Motor 22.

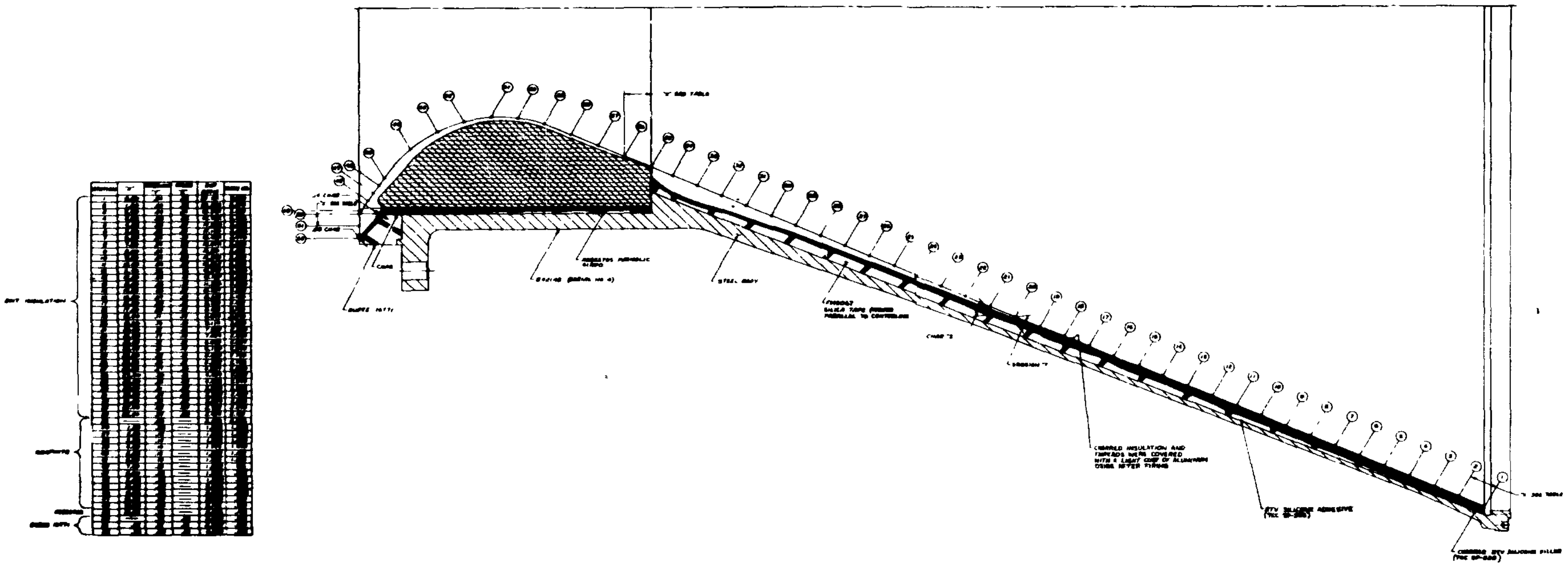


Figure 7A. Erosion Profile of Nozzle Assembly Used on TX354 Motor 22.

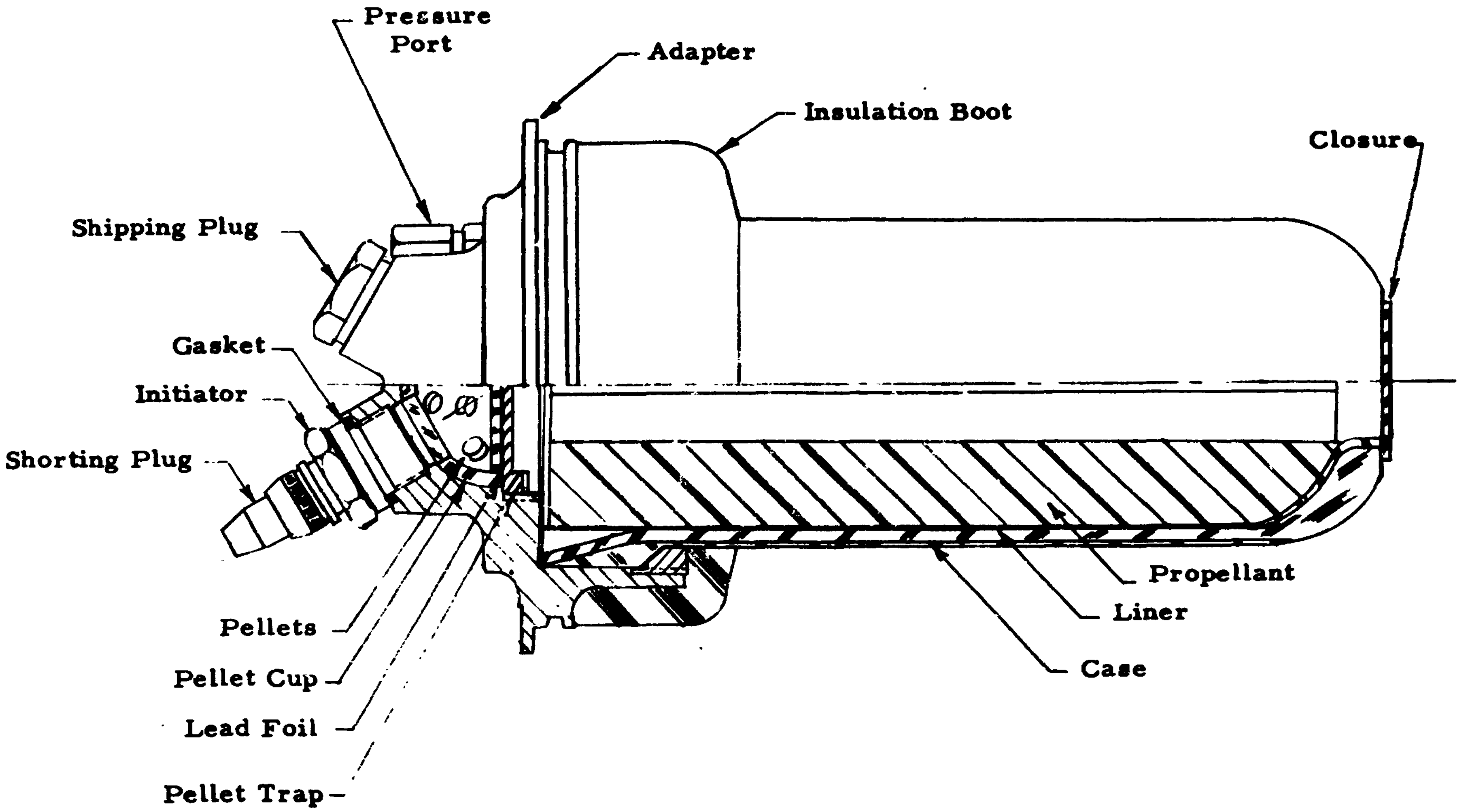


Figure 8. TX362 Pyrogen Ignition System.

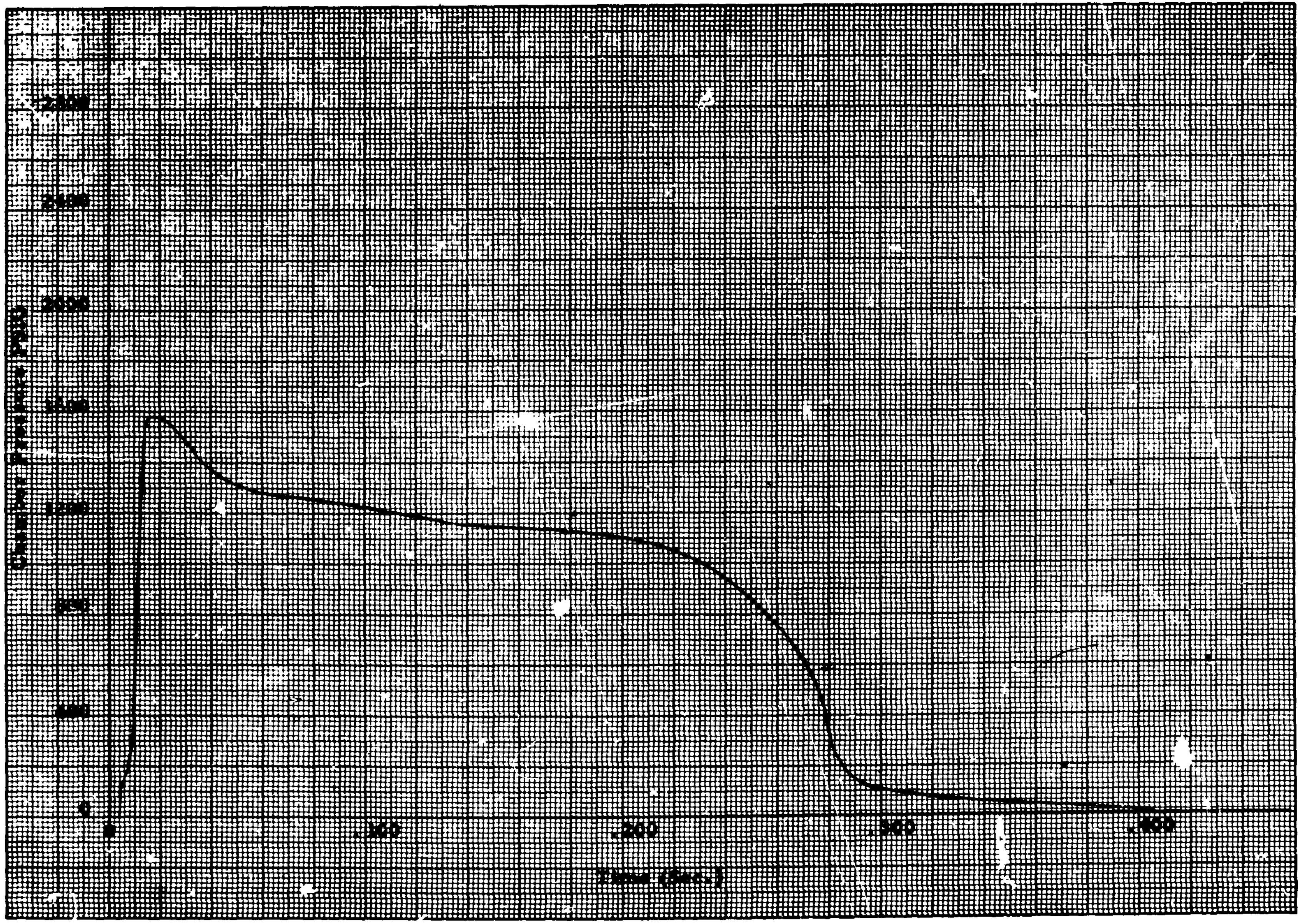


Figure 9. Typical Pyrogen Igniter Versus Time Curve.

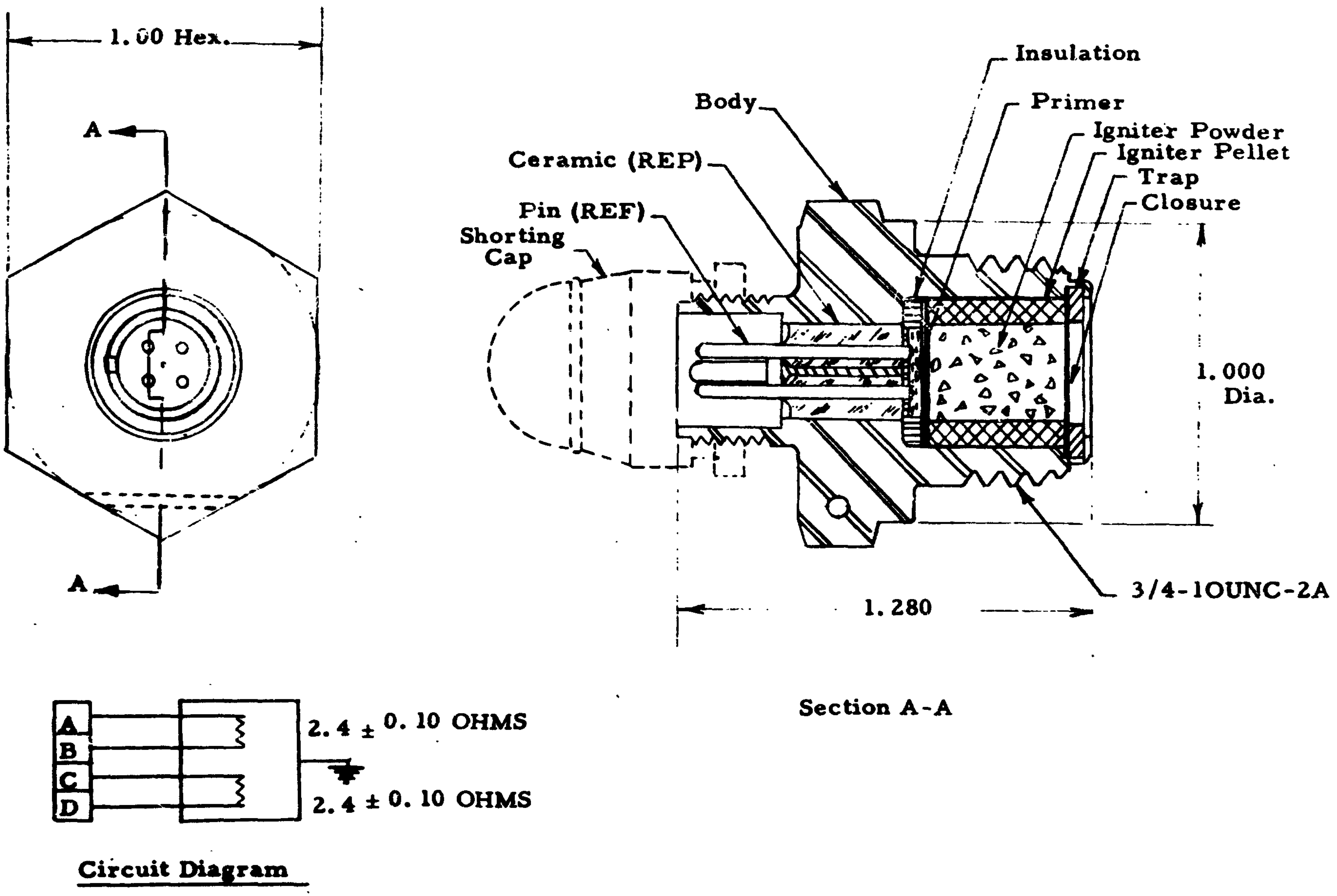


Figure 10. Electric Initiator (CR-38682).

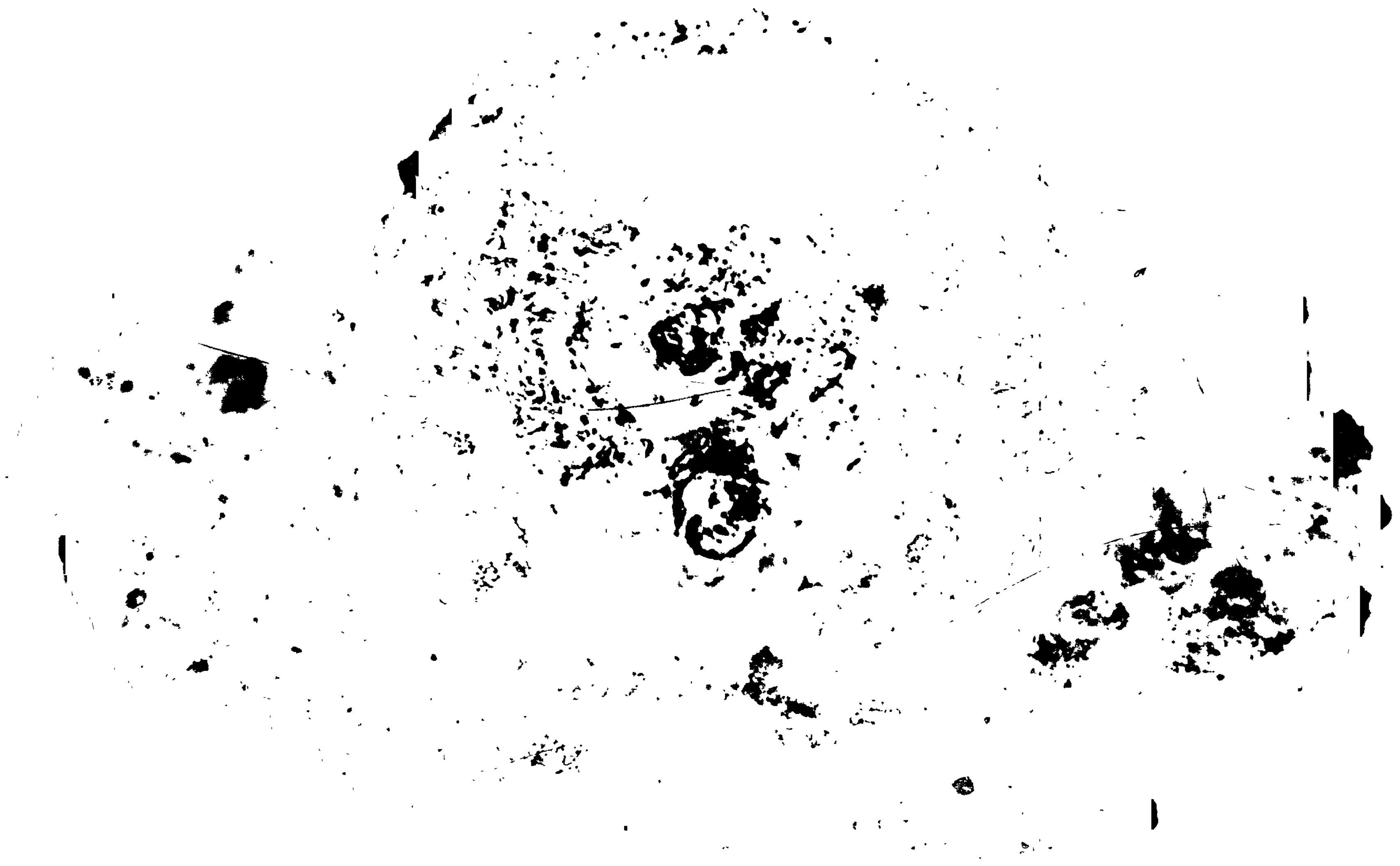


Figure 11. Pyrogen Nozzle Section, TX354 Motor 6.

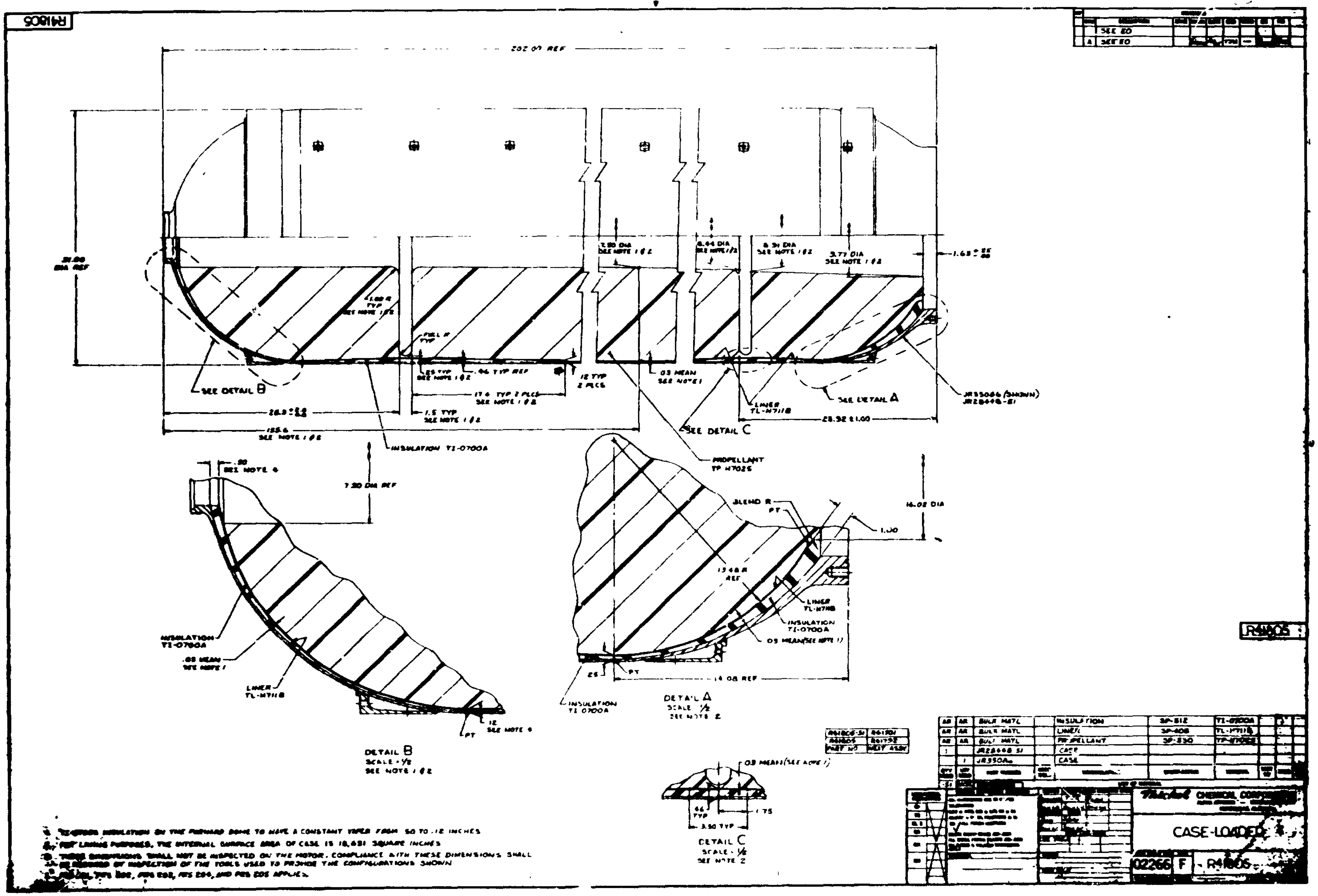


Figure 12. Original Propellant Configuration of the TX354 Castor IIA Design.

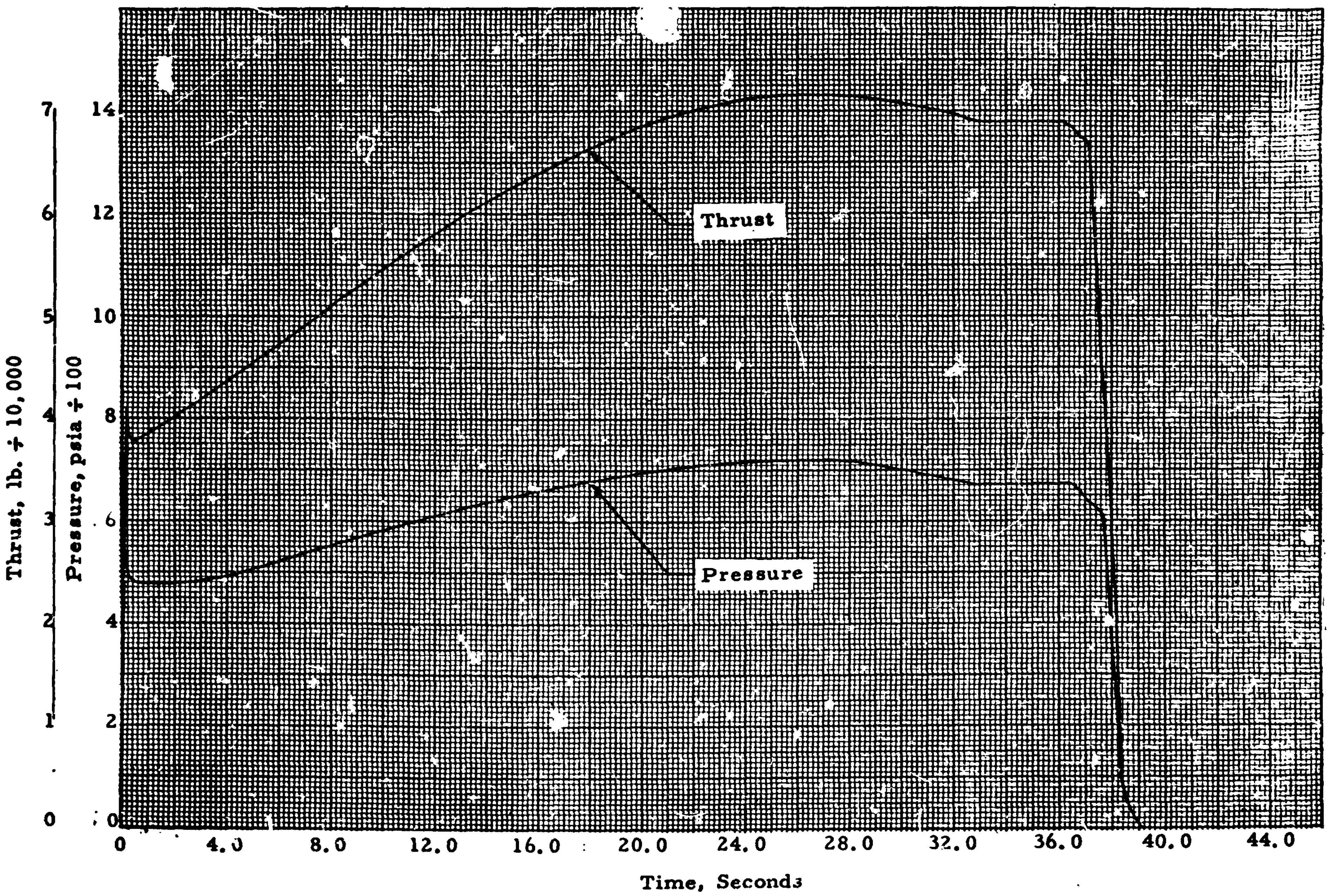


Figure 13. Typical Trace of Pressure and Thrust versus Time at 77°F Vacuum for TX354 Motor.

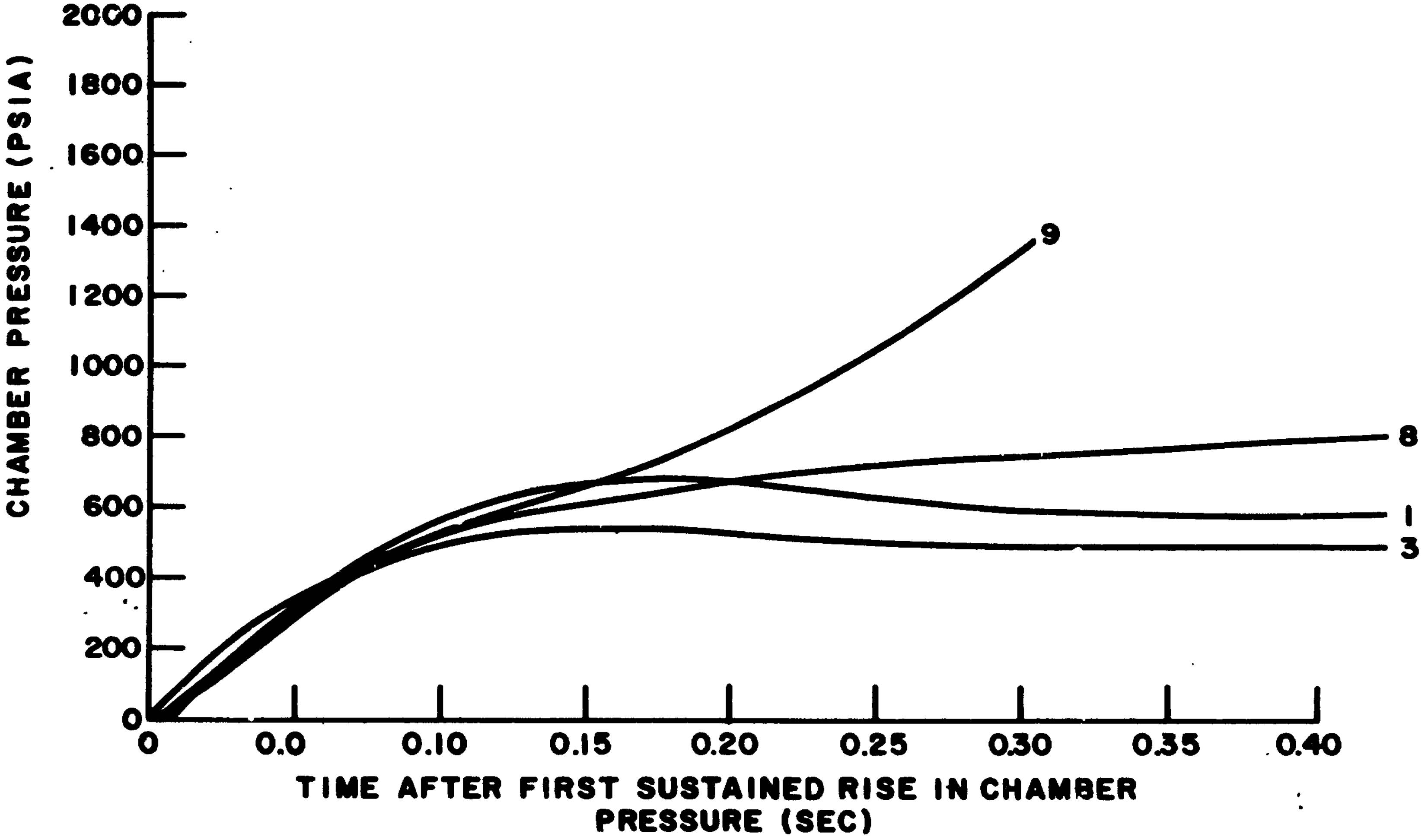


Figure 14. Variation in Chamber Pressures During Ignition Period for TX254 Motors 1, 3, 8, and 9.

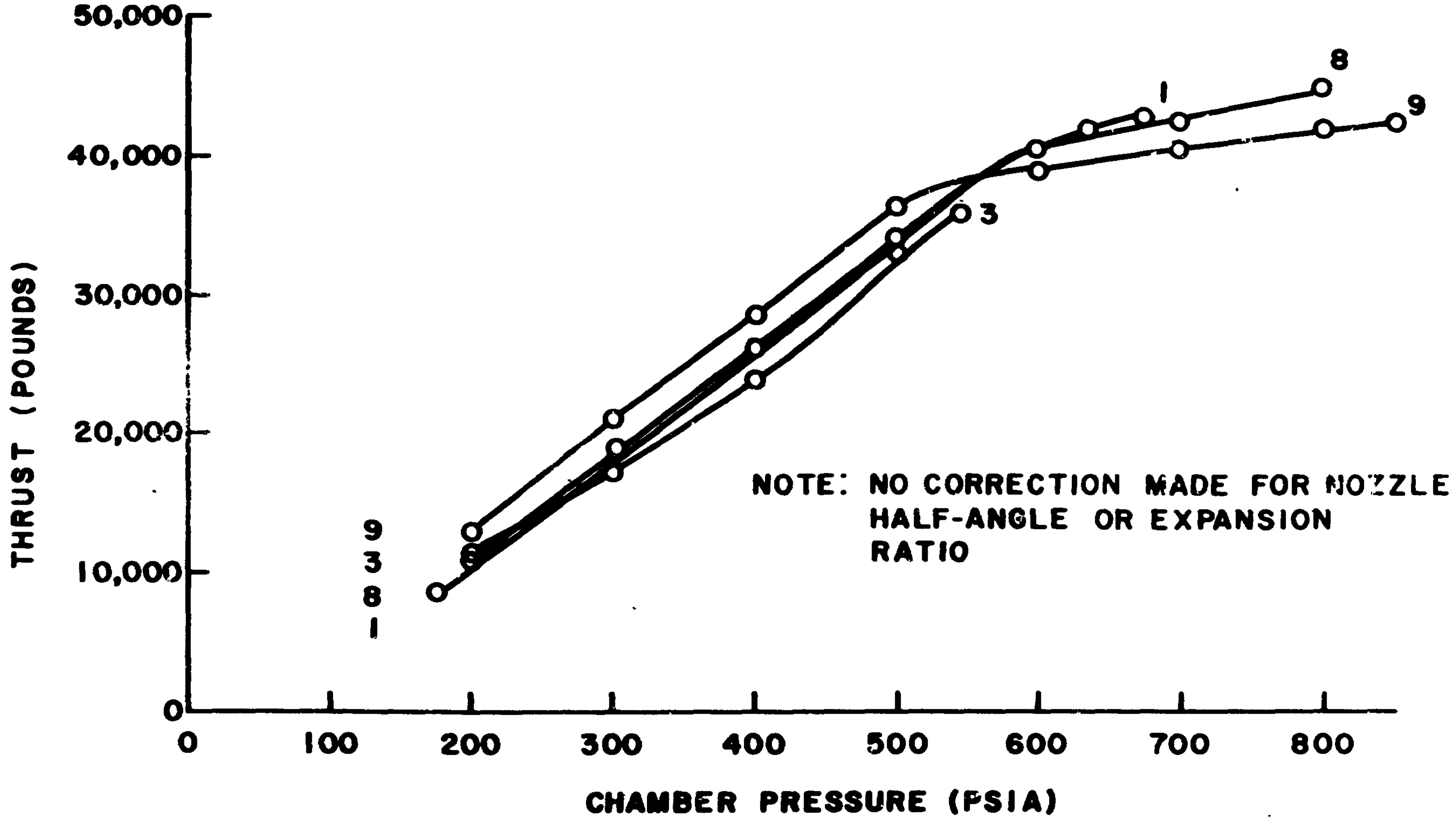


Figure 15. Variation in Thrust with Chamber Pressure for TX354 Motors 1, 3, 8, and 9.

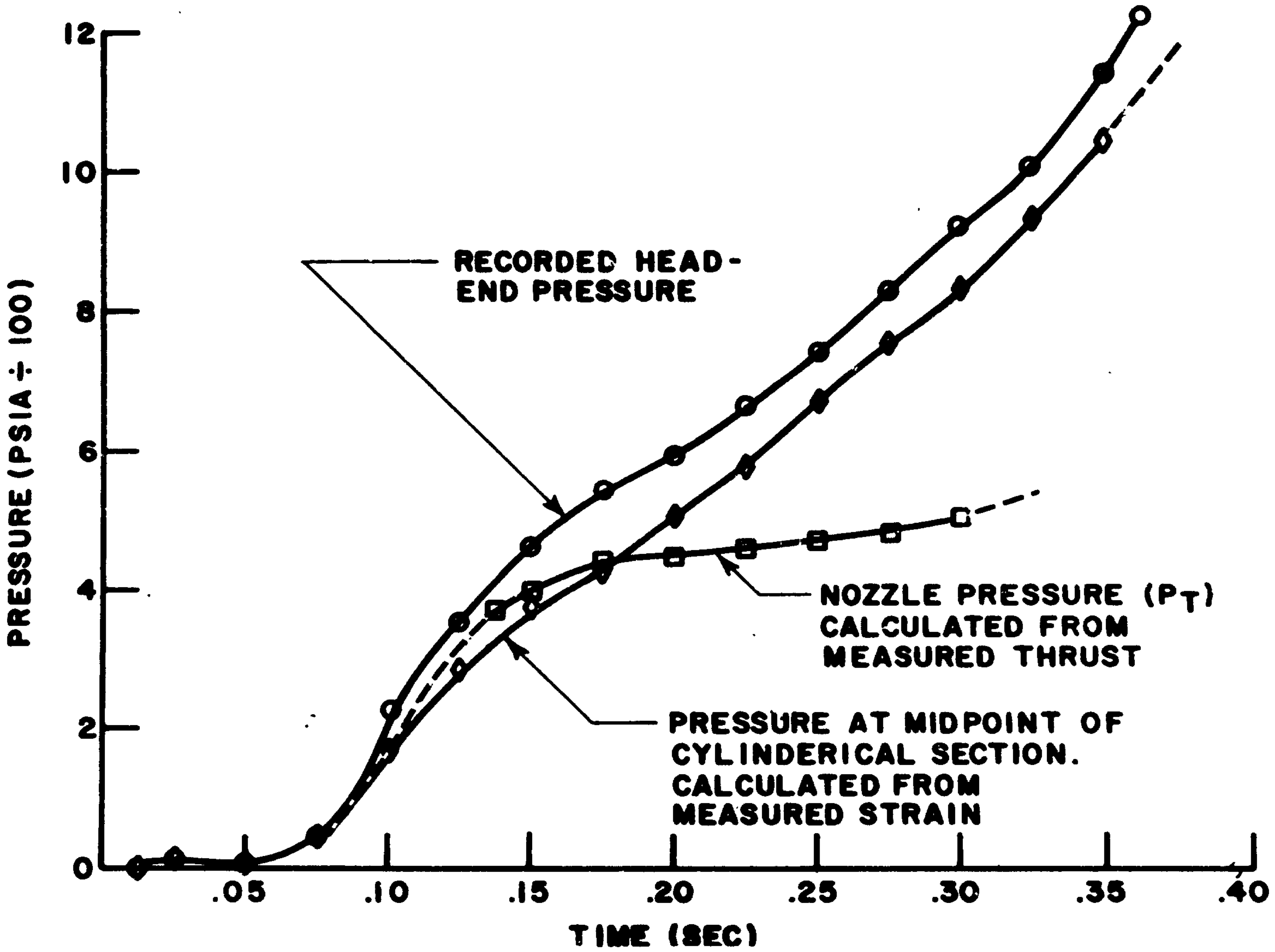


Figure 16. Comparison of Pressures Recorded at Three Stations in TX354 Motor 9.

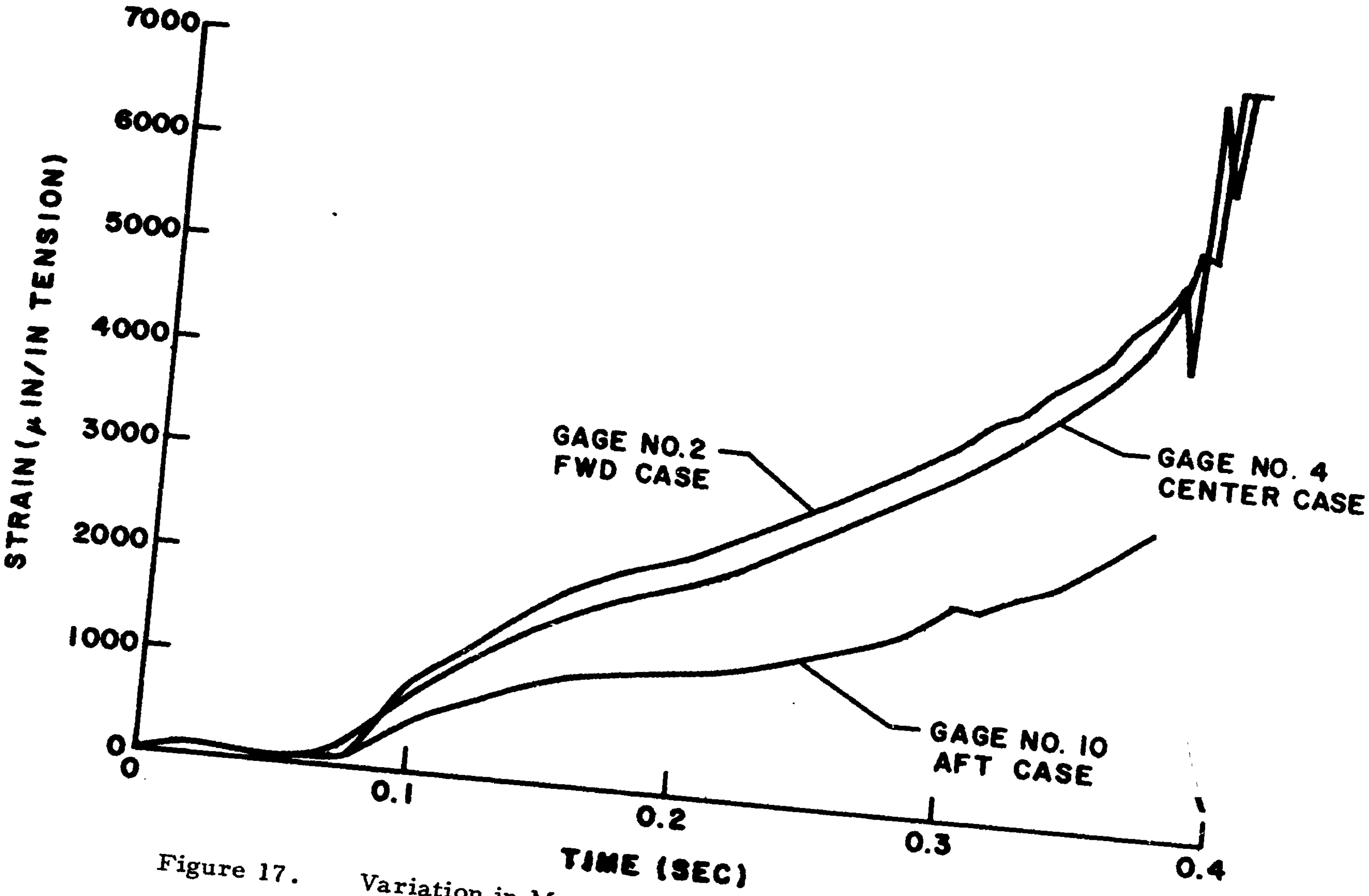


Figure 17. Variation in Measured Strains with Time at Three Stations on the Case of TX354 Motor 9.

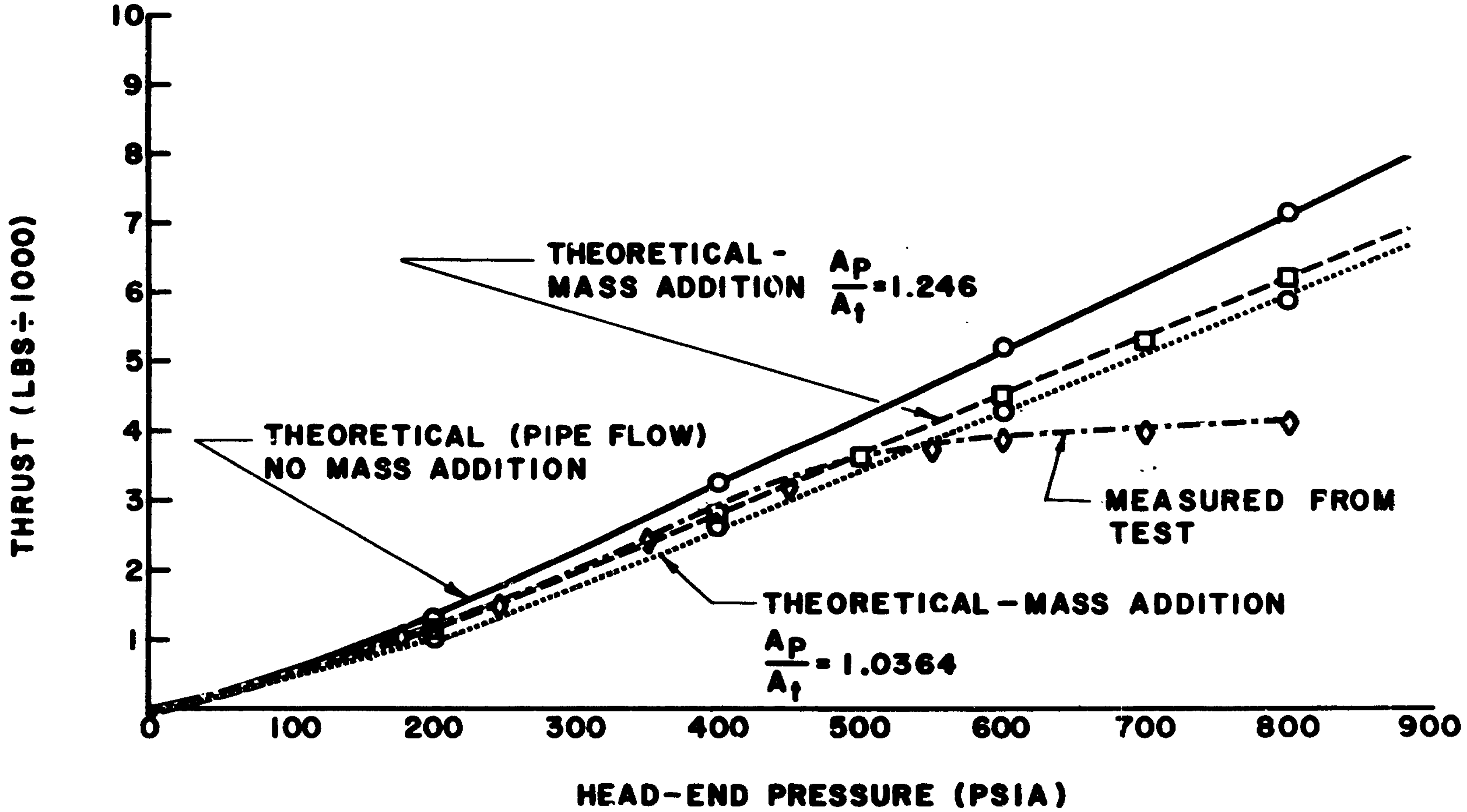


Figure 18. Comparisons of Head-End Pressure and Thrust for Theoretical and Actual Motor Performance in TX354 Motor 9.

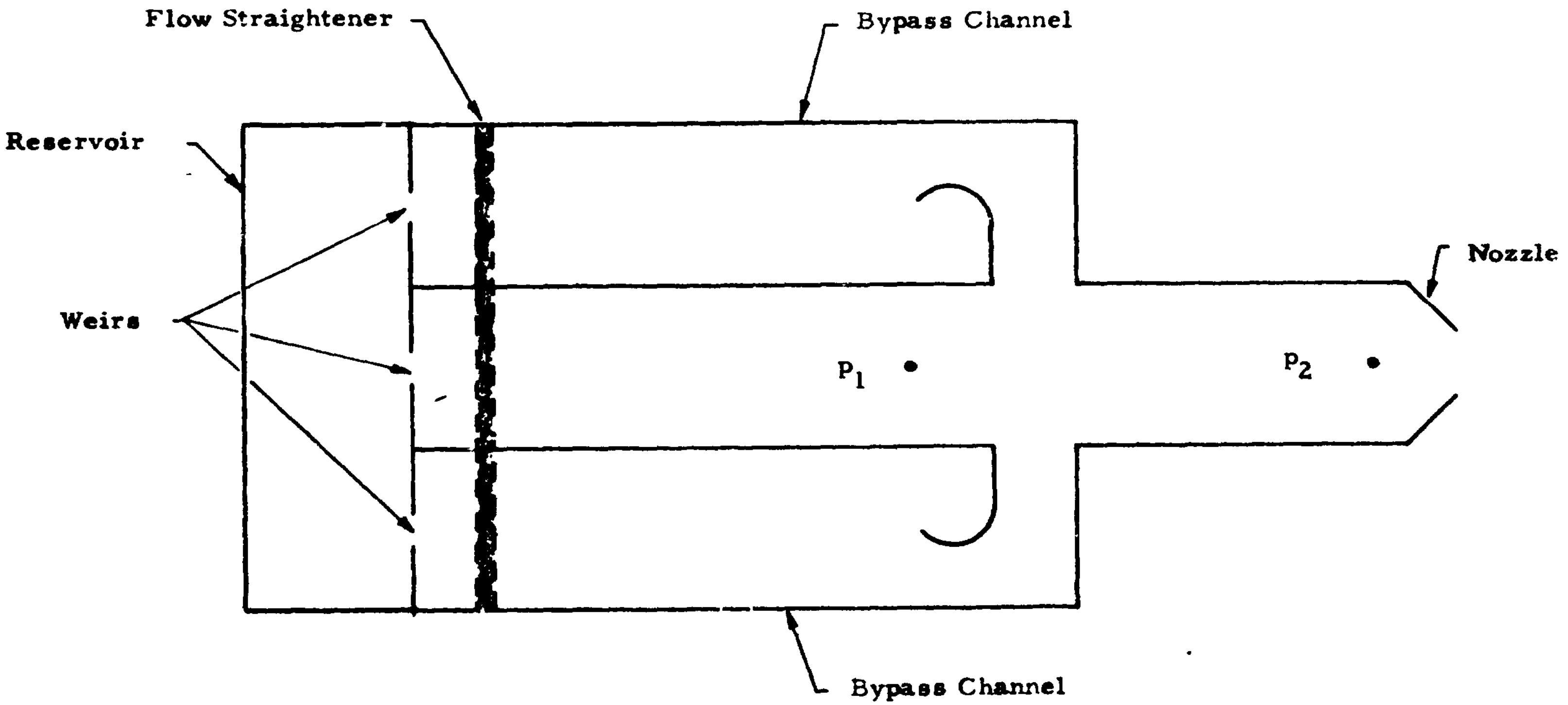


Figure 19. Schematic Diagram of Water Table Setup.

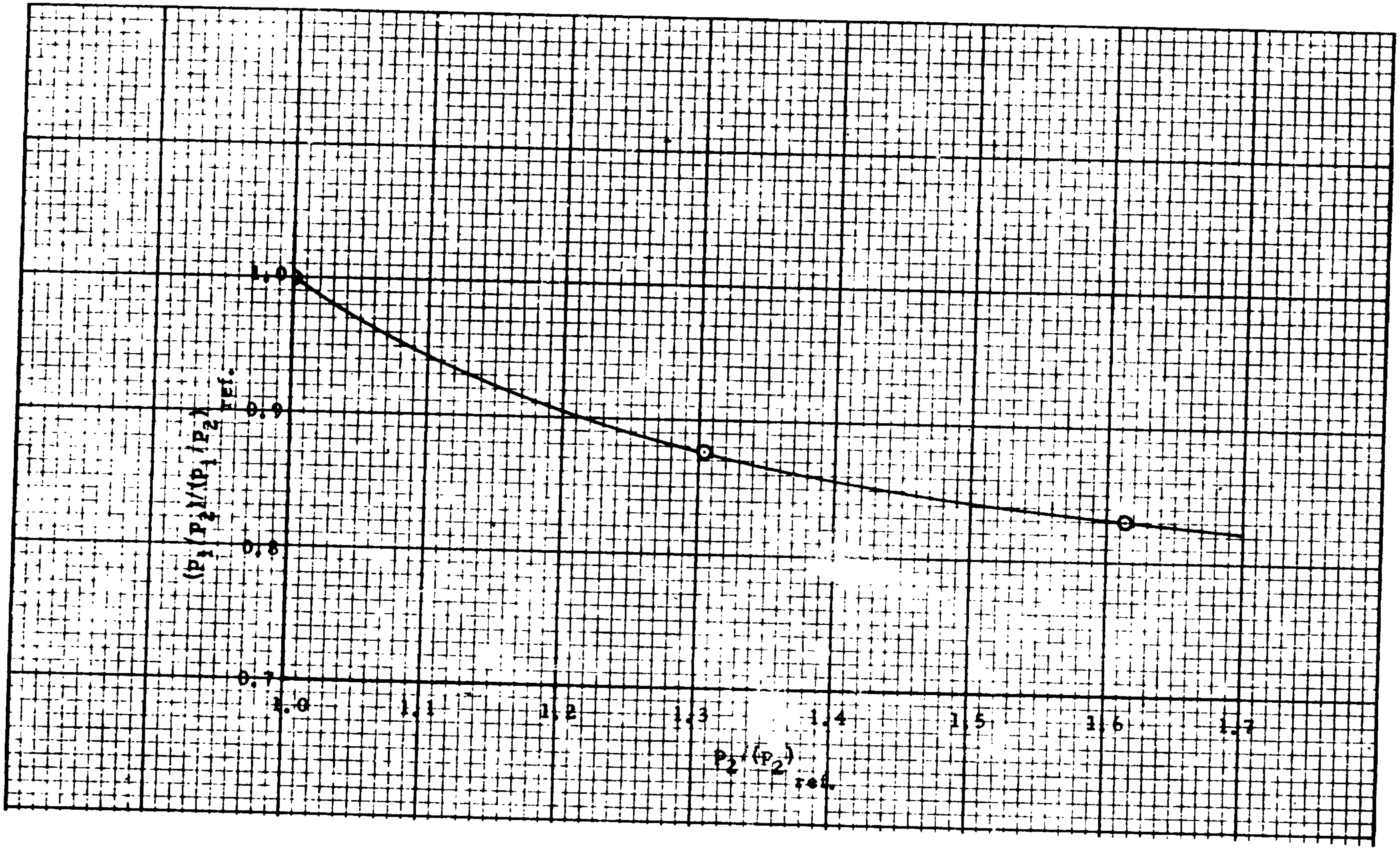


Figure 20. Effect of Downstream Static Pressure on the Pressure Ratio Across the Head-End Slot.

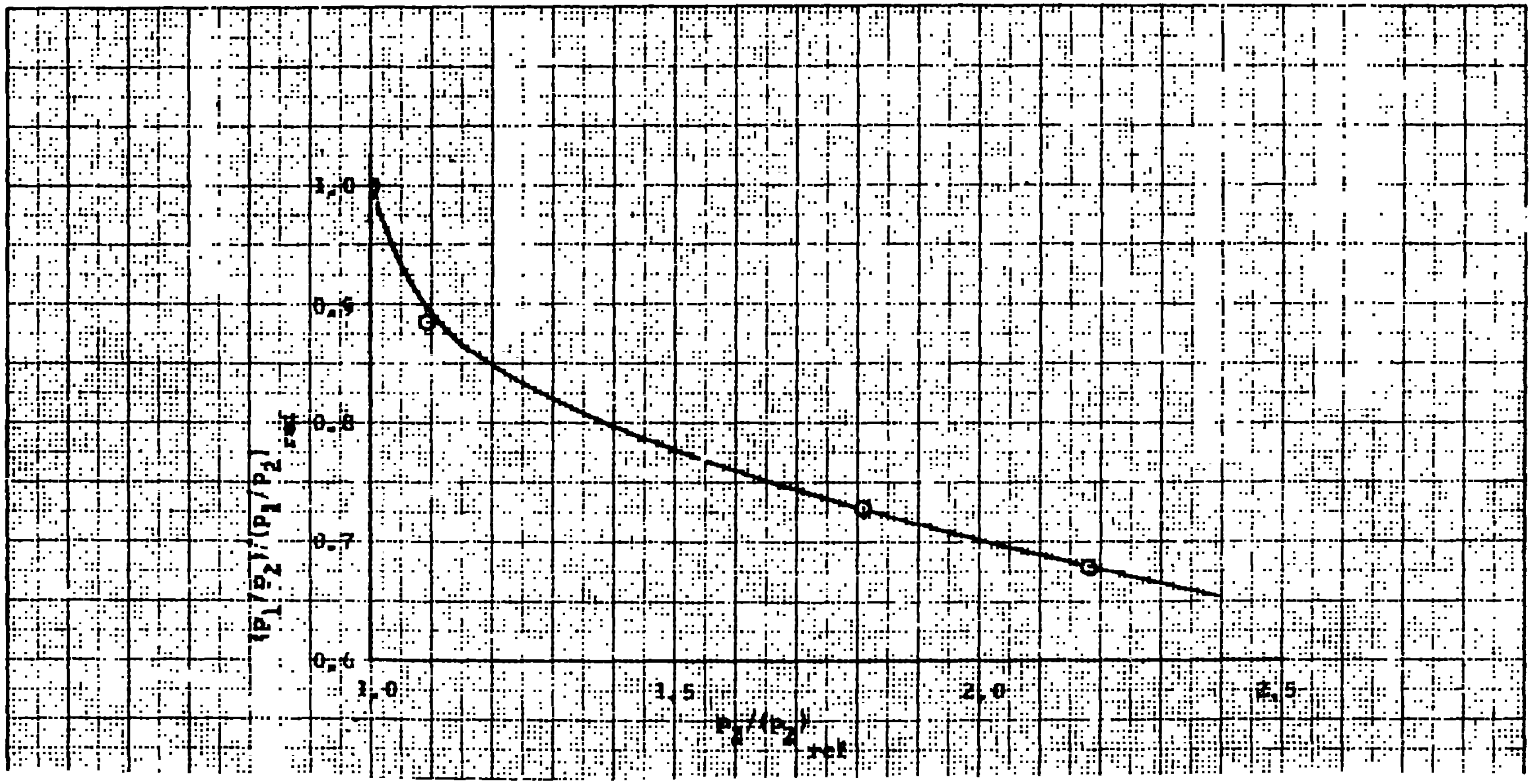


Figure 21. Effect of Downstream Static Pressure on the Pressure Ratio Across the Aft-End Slot.

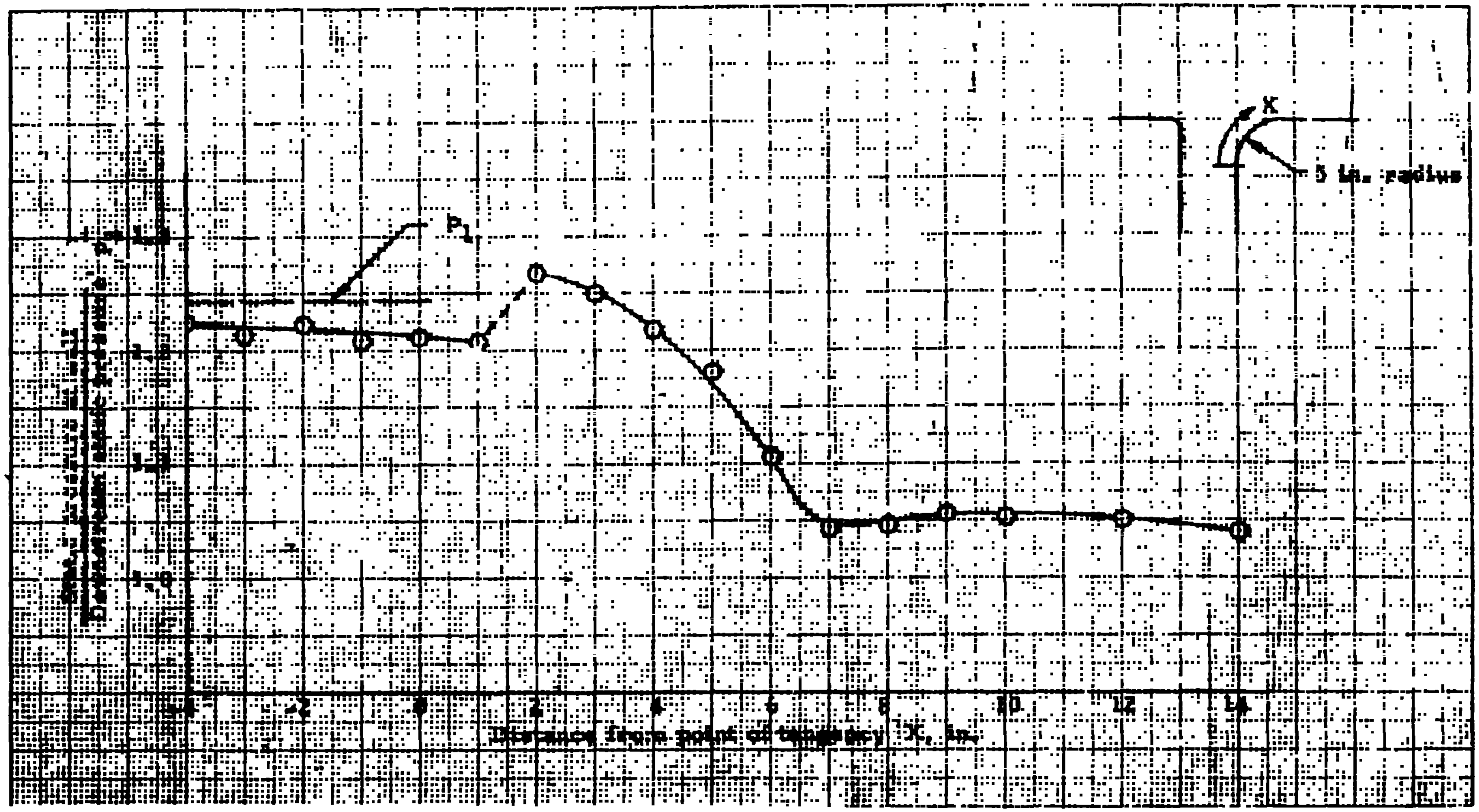


Figure 22. Pressure Distribution Along the Wall of the Aft-End Slot with a Propellant Radium of 1-Inch.

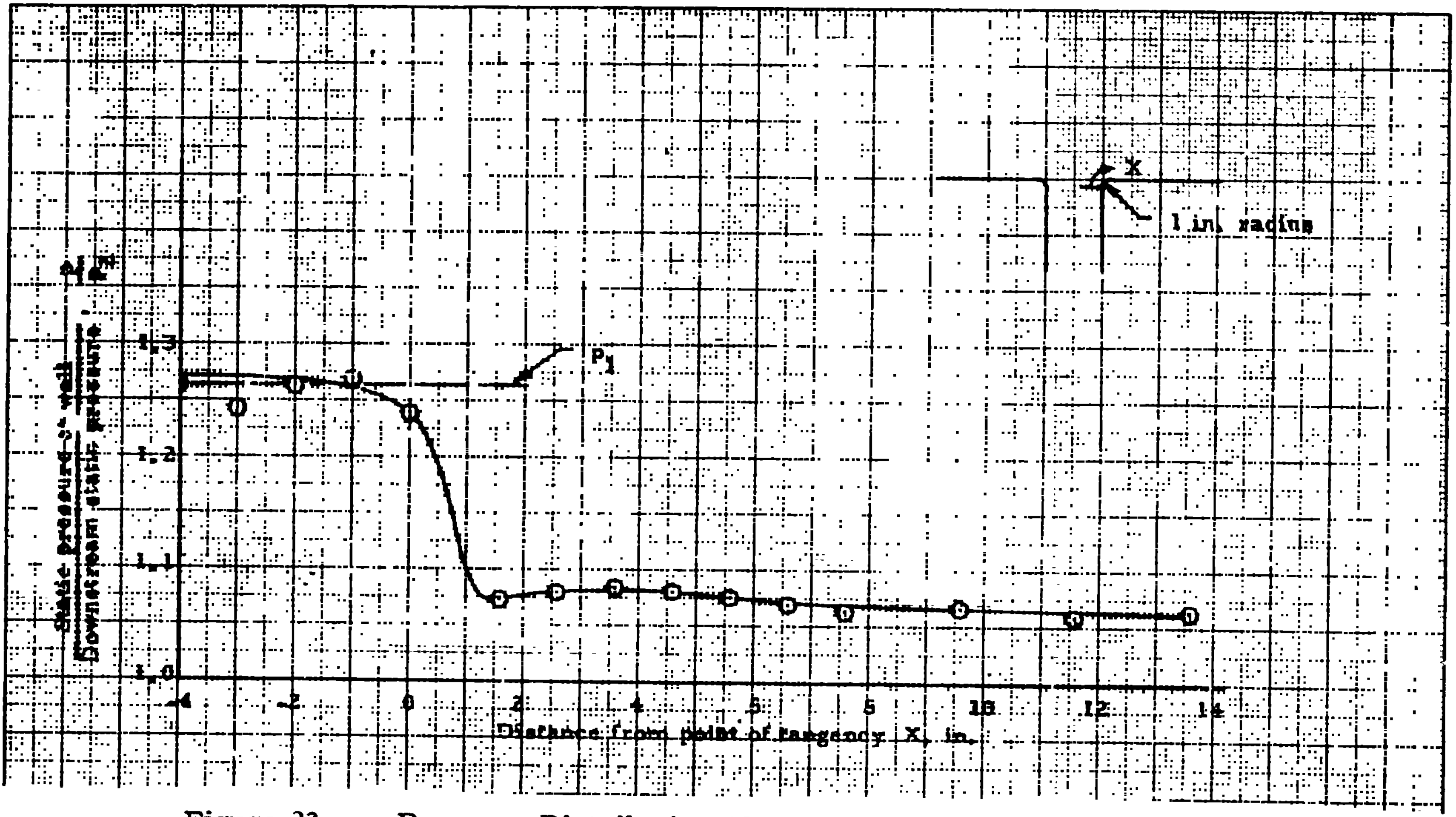


Figure 23. Pressure Distribution Along the Wall of the Aft-End Slot with a Propellant Radius of 5 Inches.

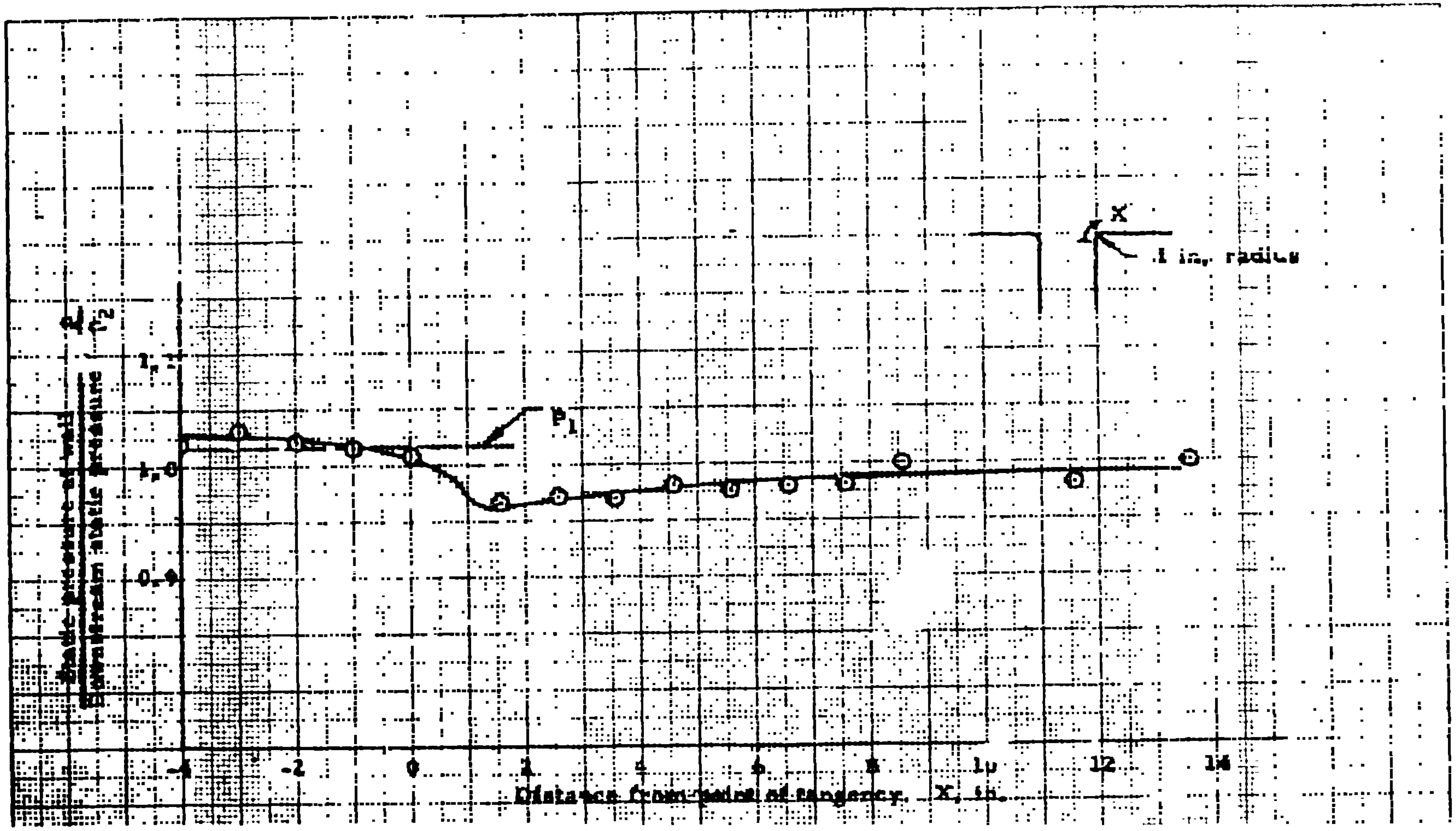


Figure 24. Pressure Distribution Along the Wall of the Forward Slot with a Propellant Radius of 1-Inch.

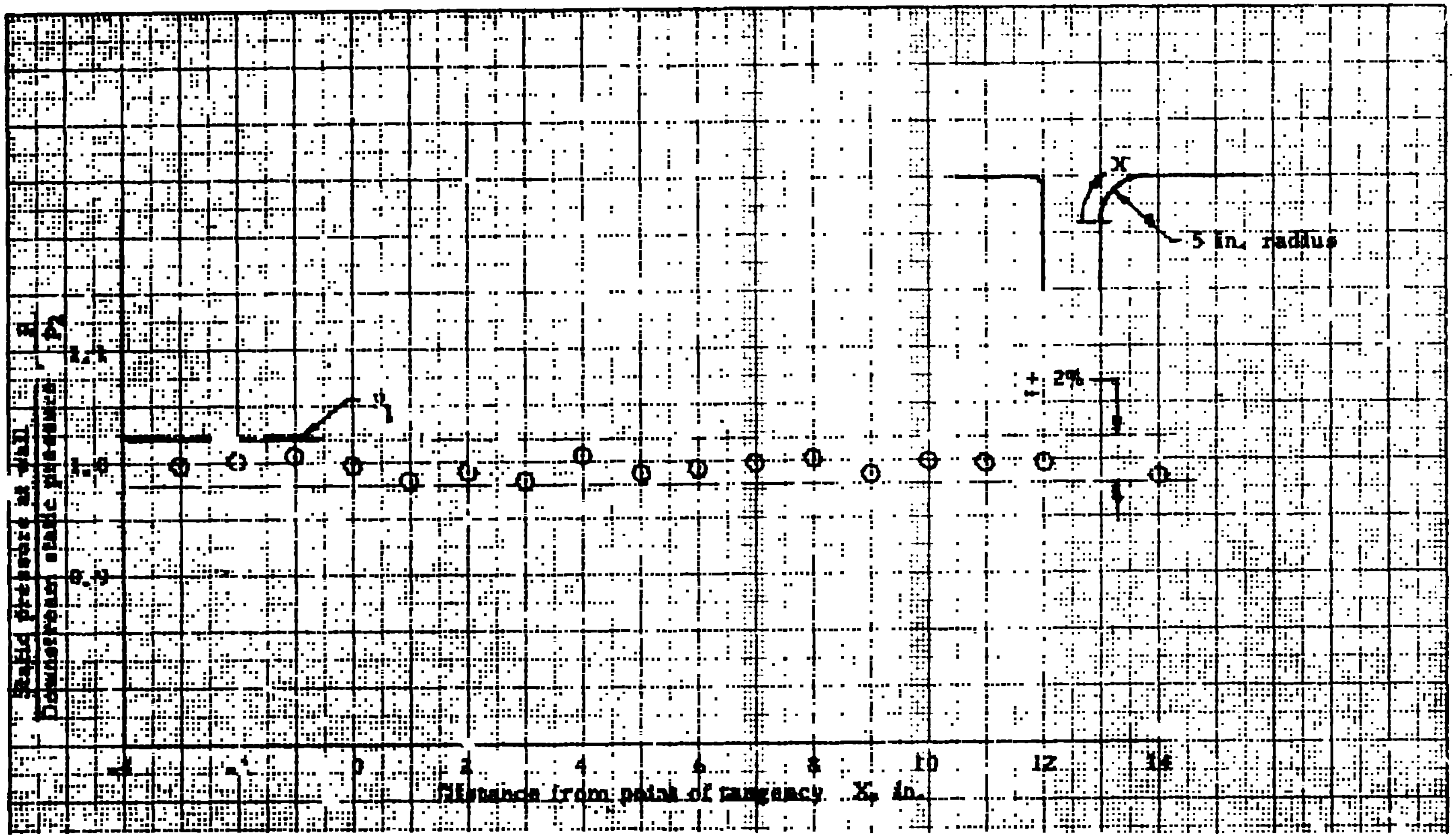


Figure 25. Pressure Distribution Along the Wall of the Forward Slot with a Propellant Radius of 5 Inches.

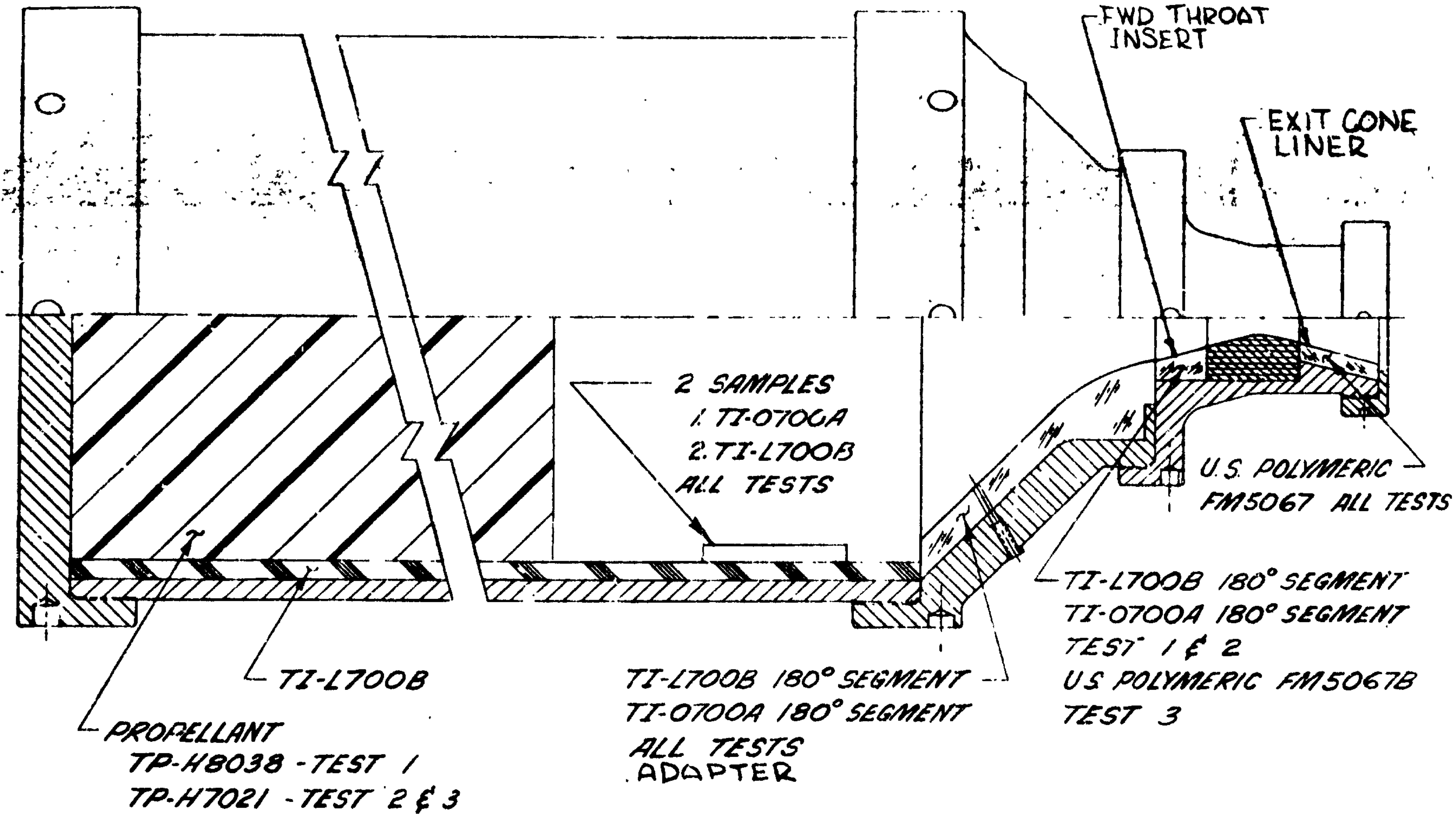


Figure 66. TX-24 Motor Cross Section.

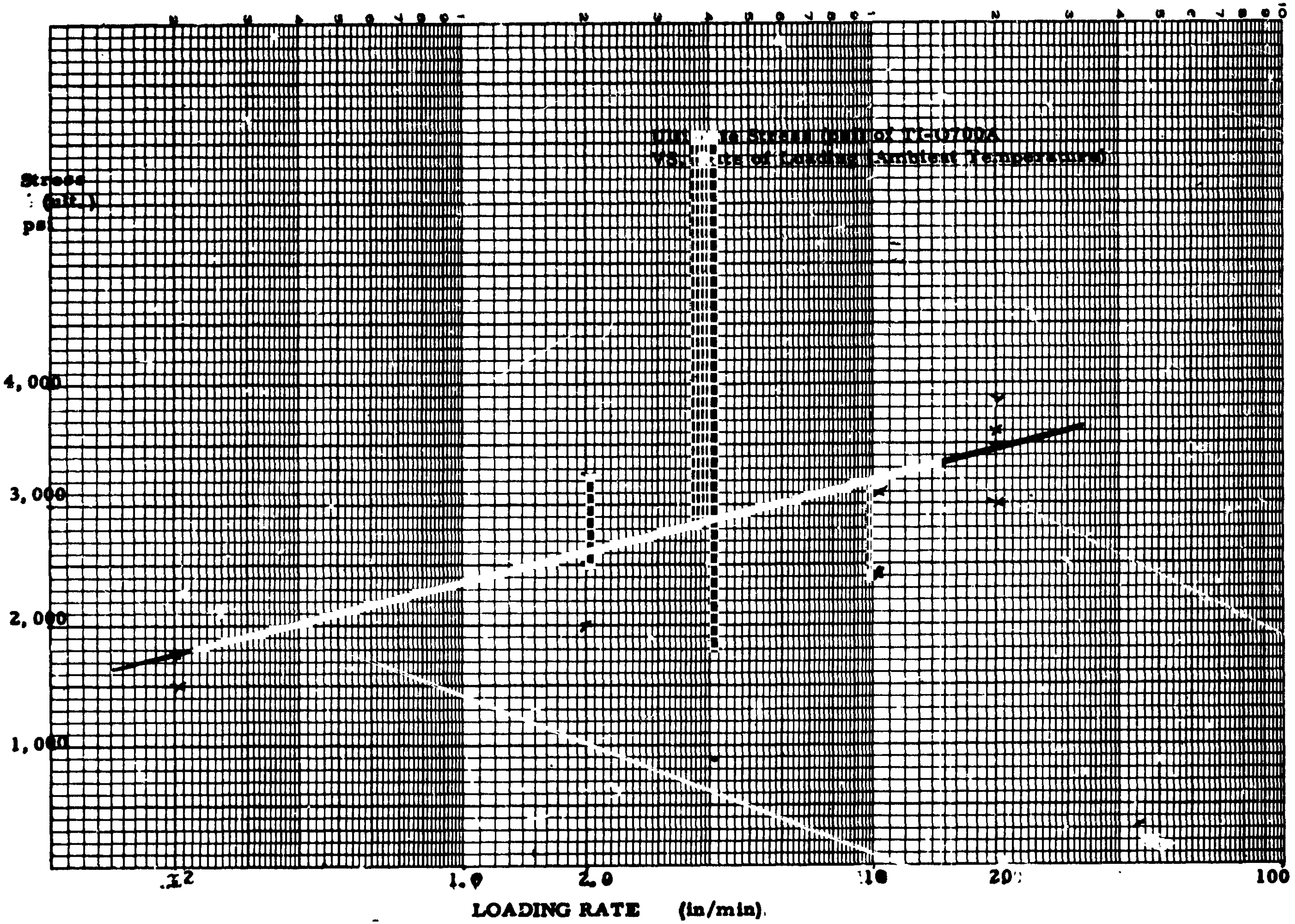


Figure 67. Ultimate Stress (psi) of TI-O700A Insulation versus Rate of Loading at Ambient Temperature.

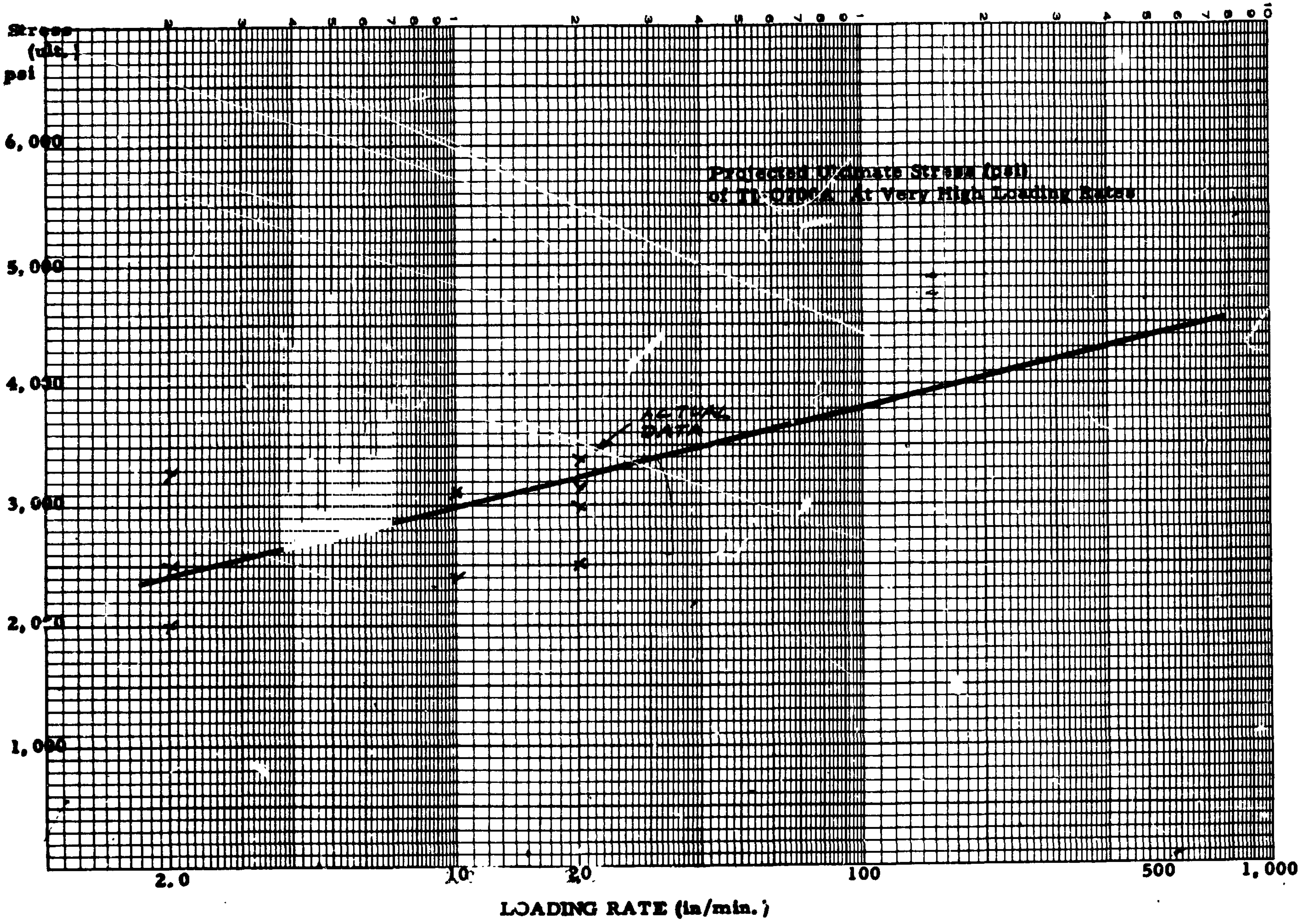


Figure 68. Project Ultimate Stress (psi) of TI-O700A at Very High Loading Rates.

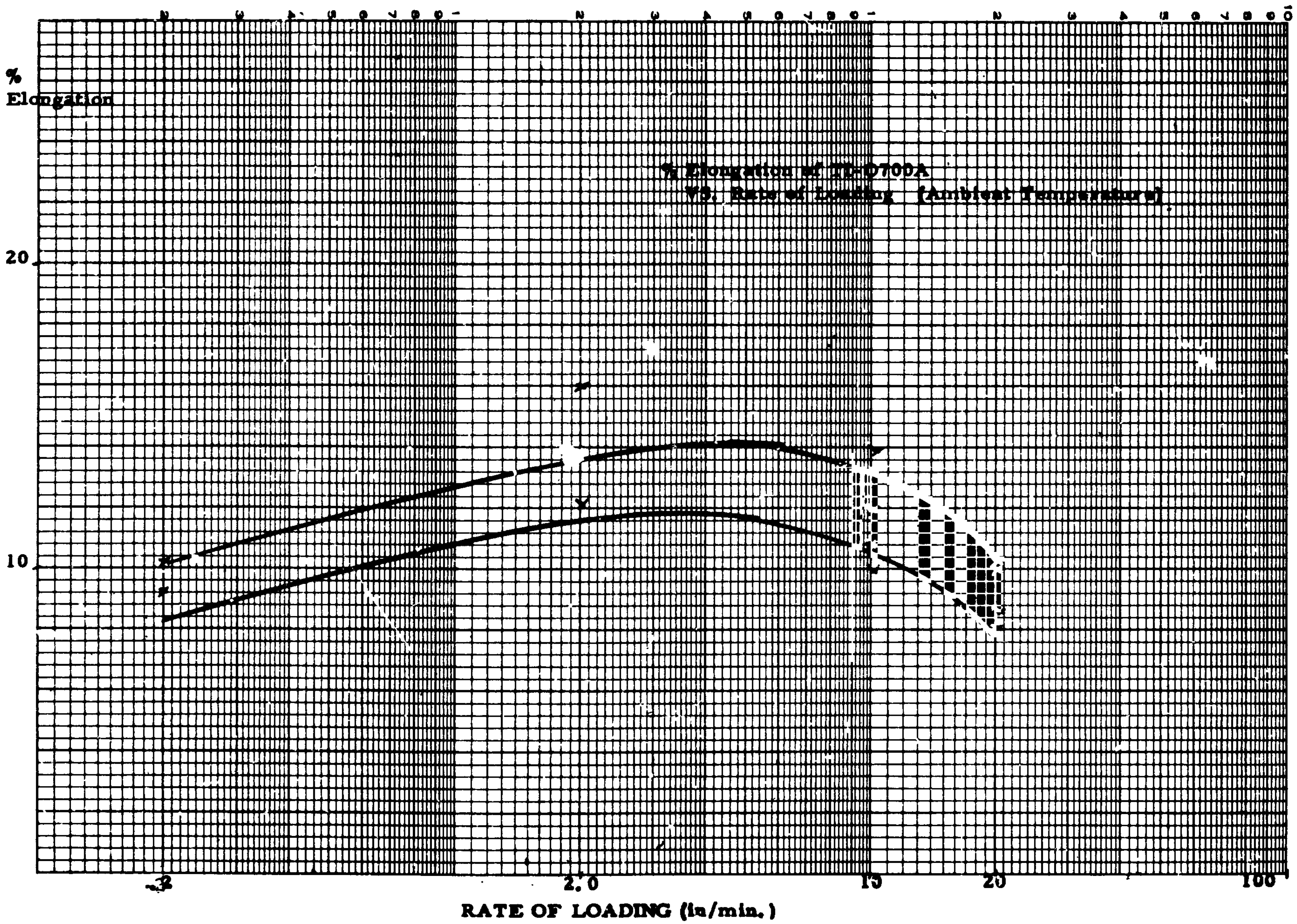


Figure 69. Percent Elongation of TI-O700A versus Rate of Loading at Ambient Temperature.

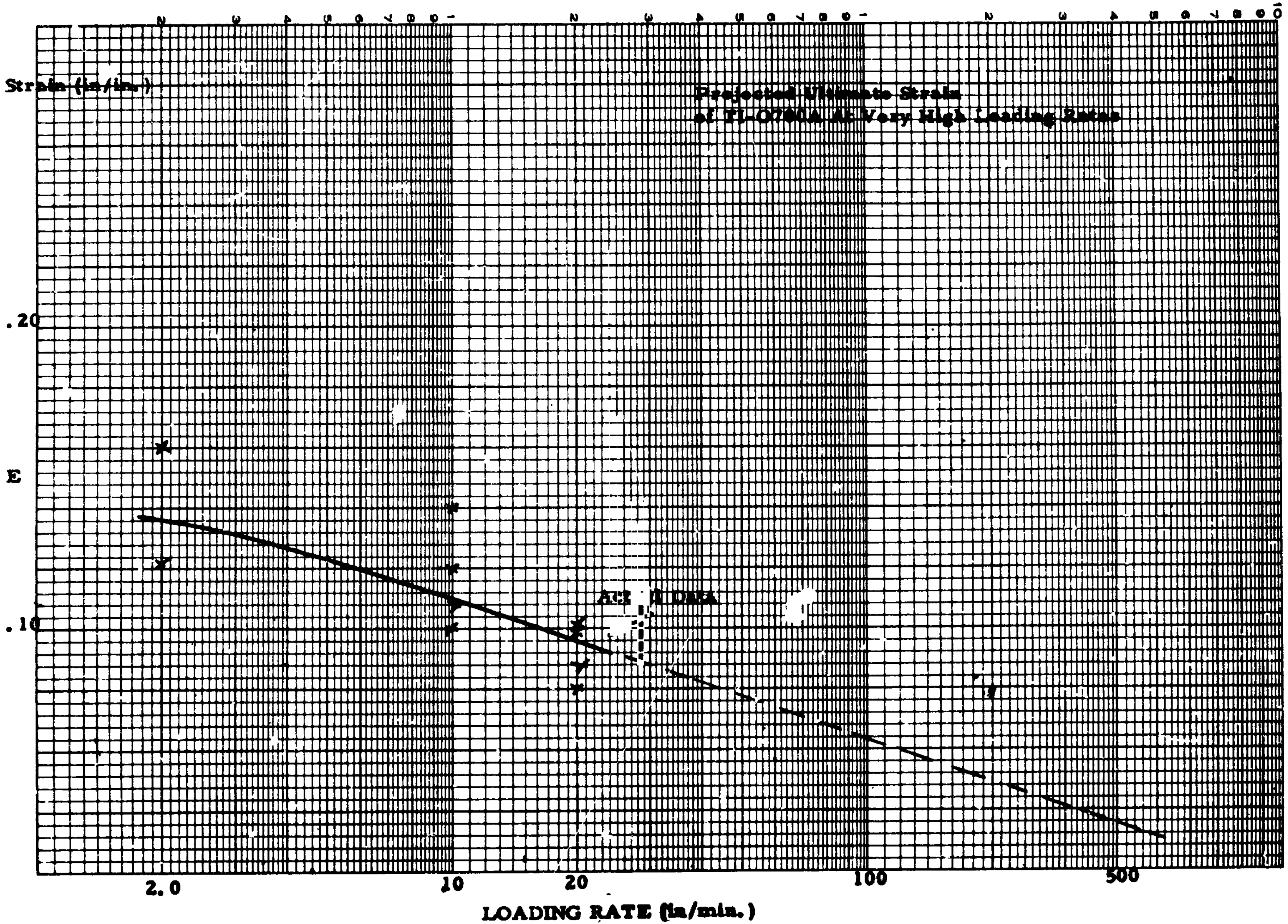


Figure 70. Projected Ultimate Strain of TI-O700A at Very High Loading Rates.

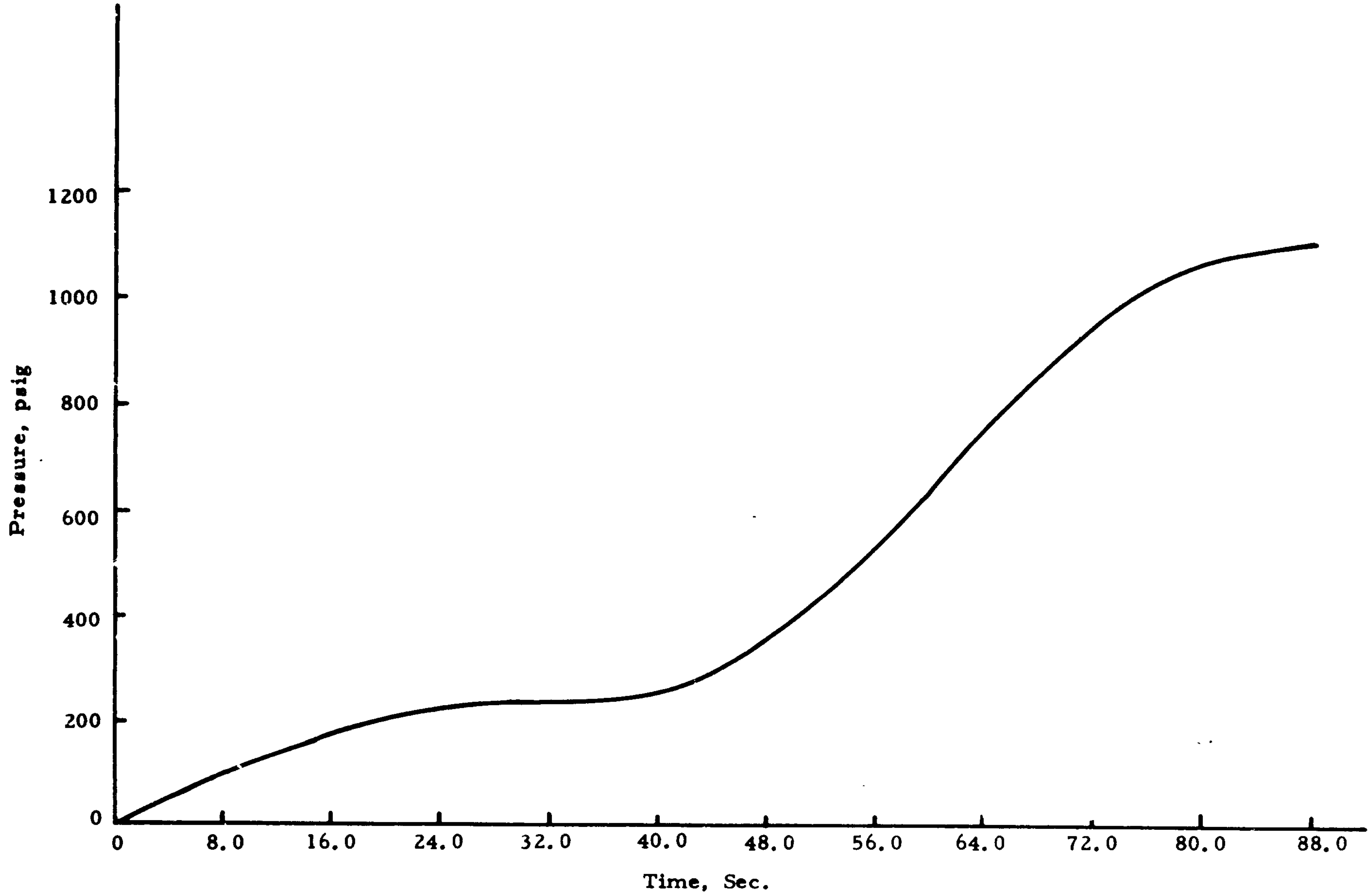


Figure 71. Pressure-Time History of Hydroburst of TX354 Motor Case S/N 433.

Figure 72. TX354 Motor Case S/N 433 After Burst.

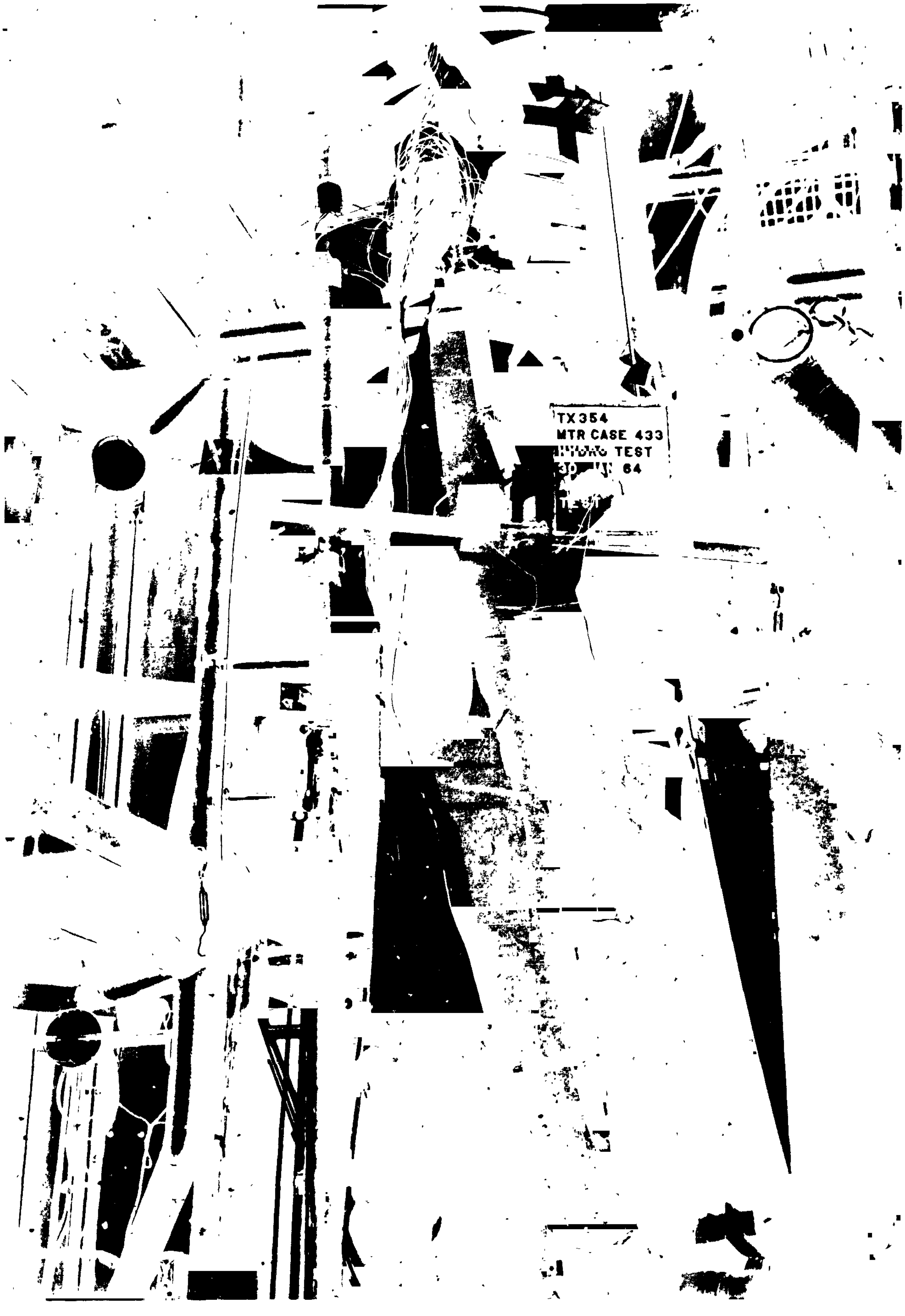
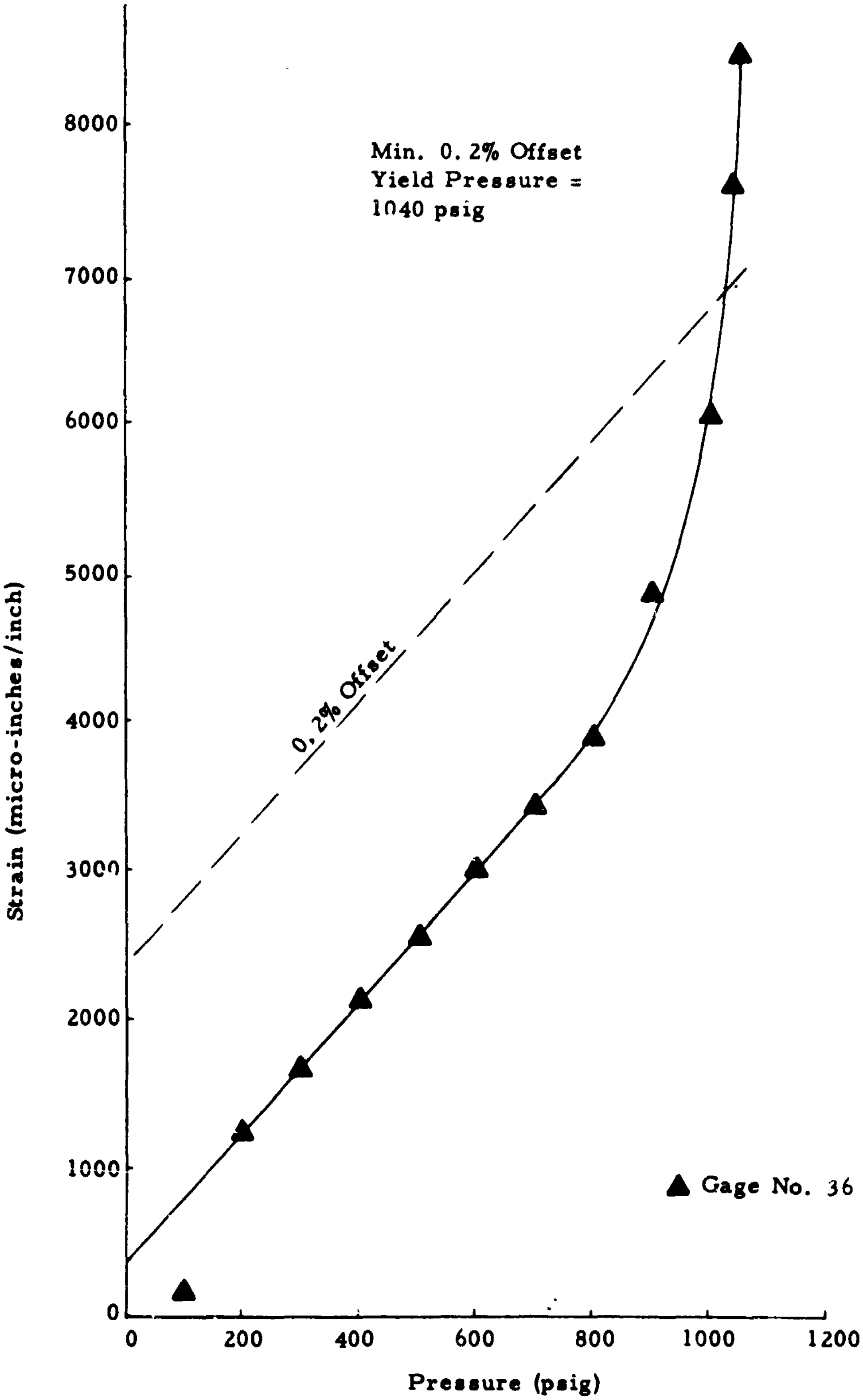


Figure 73. Closeup of TX354 Motor Case S/N 433 After Burst.

Figure 74. Closeup of Area Where Failure Originated on TX354 Motor Case S/N 433.



gure 75. Strain versus Pressure, TX354 Motor Case S/N 433.

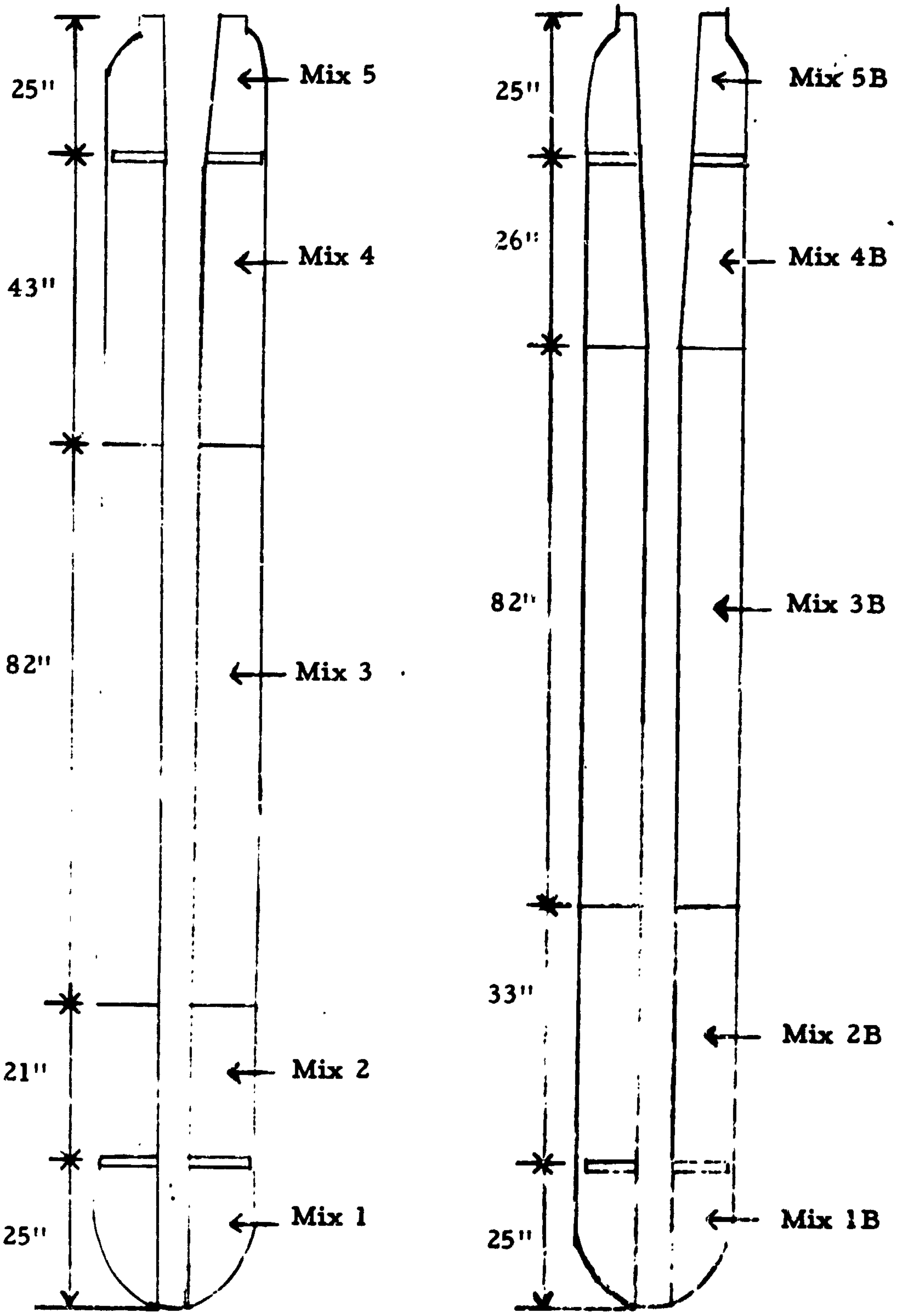


Figure 76. Typical Casting Sequence for Dual Loading of TX354 Motors.

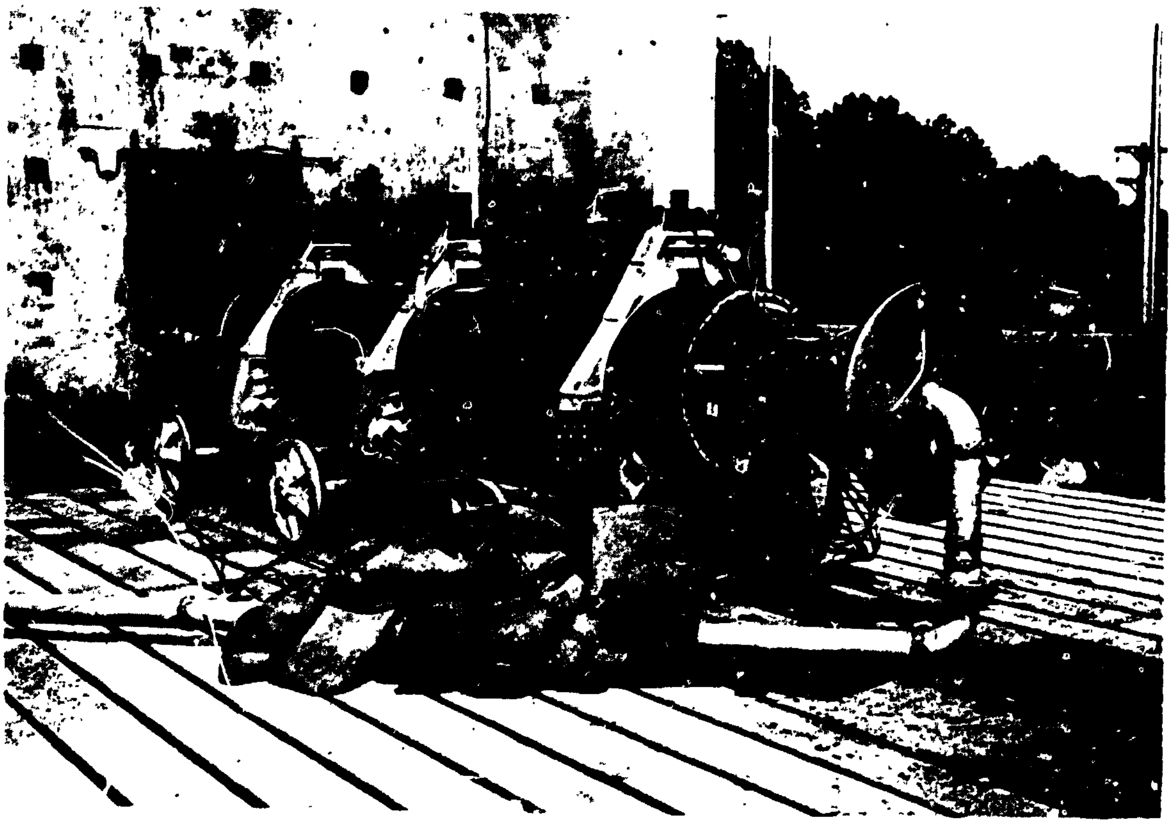


Figure 77. Photograph Showing Typical Left Side of TX354 Motor Before Test.

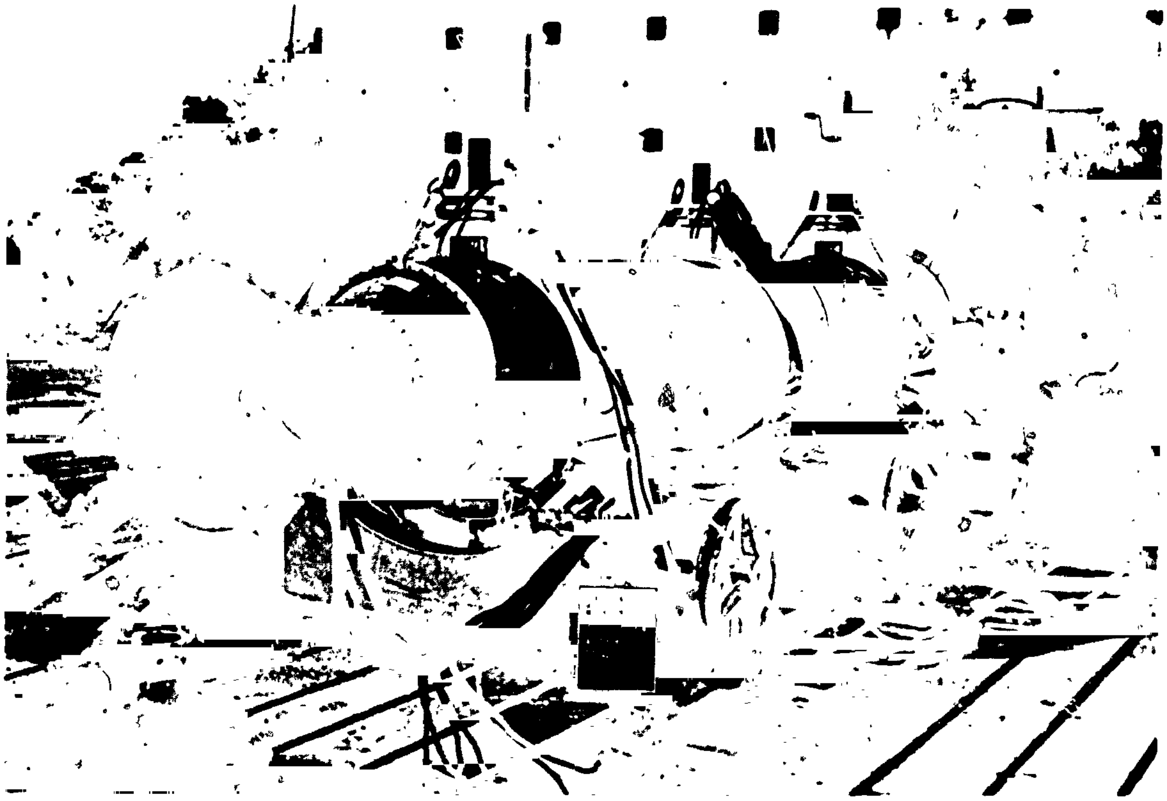


Figure 78. Photograph Showing Typical Right Side of TX354 Motor After Test.

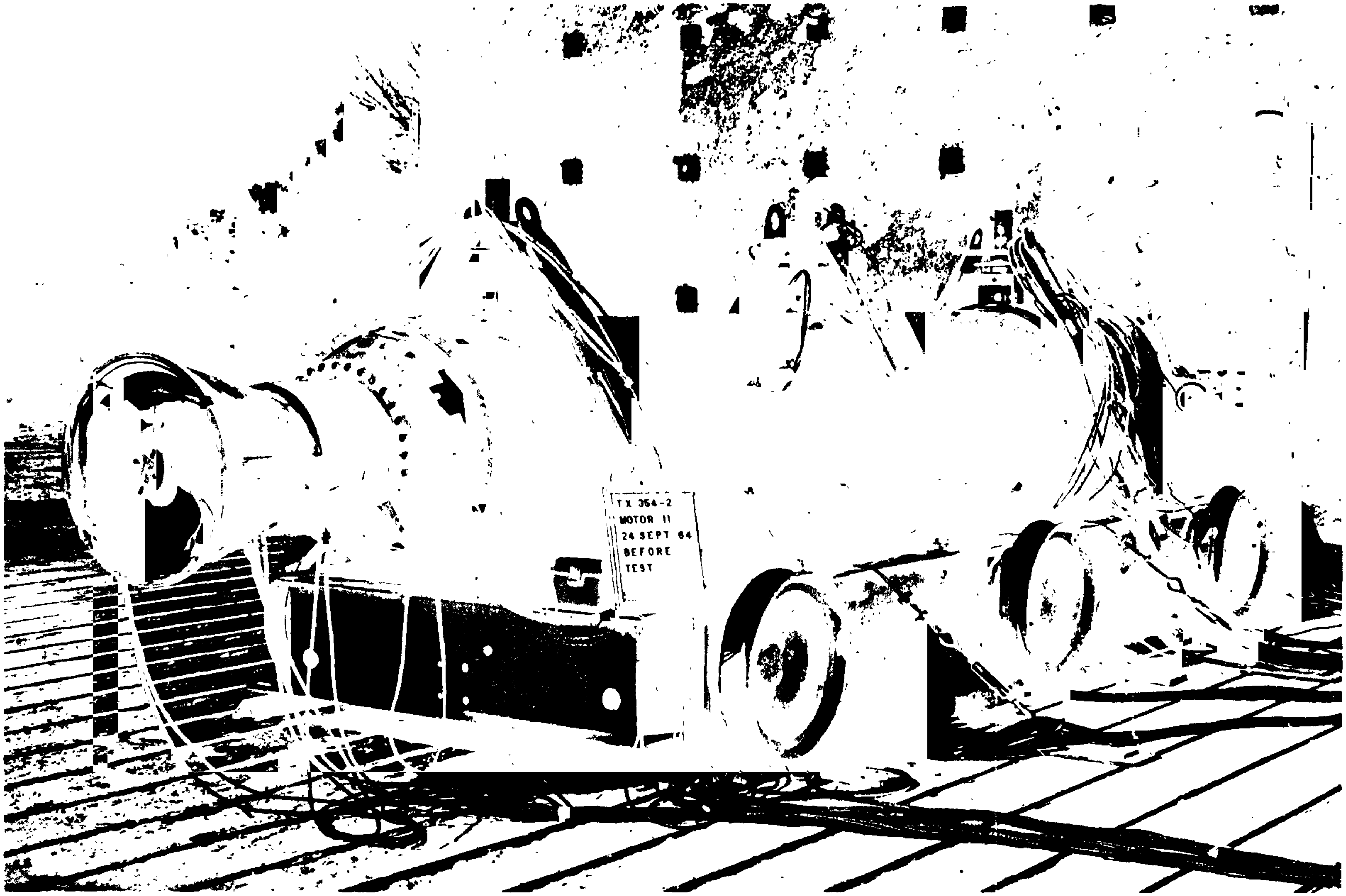


Figure 79. Another View of Typical TX354 Motor Before Test.

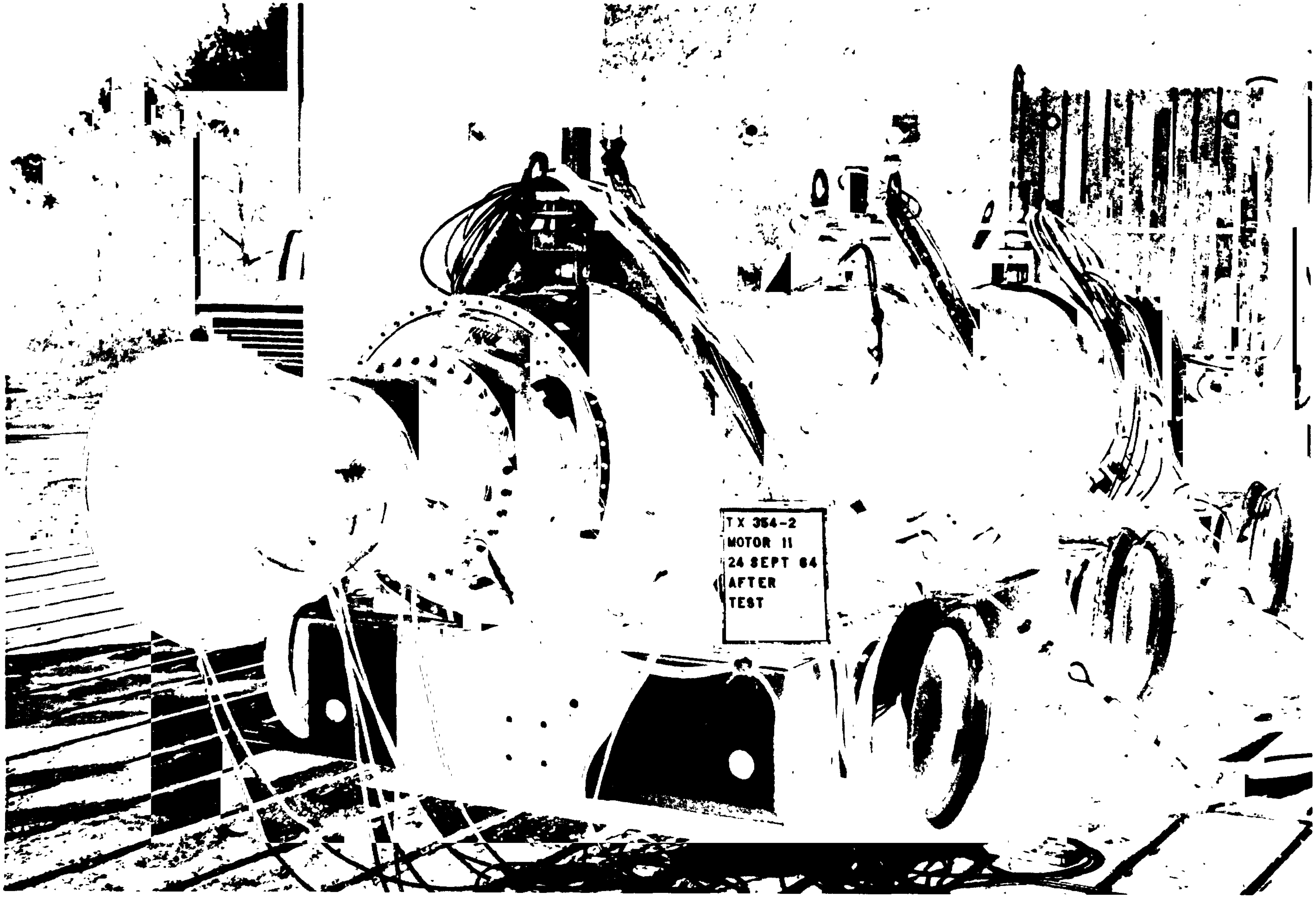


Figure 80. Typical TX354 Motor After Test.

MIX NO B2007
B2008 & B2014

CHG NO	MOTOR TYPE	PROGRAM	PROPELLANT TYPE	DATE FIRED	DATE CAST	Wp (LB)	Wb (LB)	% PROPELLANT RESIDUE	TEMPERATURE (°F) GRAIN	TEMPERATURE (°F) AMB	BAR PRESS IN" Hg	% R H
1	[redacted]		TP-H7021	3-12-64		8333.72			75	60	30.20	46
	TX3=4 #											

NOZZLE DIA (IN) BEFORE	NOZZLE DIA (IN) AFTER	$\bar{A}_t$ (IN²)	ΔA_t (IN²)	A_e/A_t	$A_e/\bar{A}_t$	1/2 ∠	IGNITER	$t_{d50\%}$ (SEC)	$t_{50\%-web}$ (SEC)	t_{apr-o} (SEC)	P max (PSIA)	P50%-web (PSIA)
8.760 8.758 8.758	9.011 9.010 9.012	62.314	+3.517	6.551	6.366	22°24'	TX-362 J2677-15 S/N 1	0.122	36.662	39.370	693	591

$\int Pdt_1$ (PSIA-SEC)	$\int Pdt_2$ (PSIA-SEC)	C* (FT/SEC)	Fmax (LB)	F50%-web (LB)	I (LB-SEC)	Isp (SEC)	r (IN/SEC)	Cf	Cd	*** t_{id} (SEC)	$t_{i\,10\%}$ (SEC)	$t_{i\,70\%}$ (SEC)	$t_{i\,90\%}$ (SEC)	t_b (SEC)	t_f (SEC)
21670	21970	5259	59760	51800	1,919,000	230.3	0.316	1.413	0.940	0.019	0.085	0.148	0.194	36.730	38.614
			*457	* 386	*14240										

$\bar{r}$ (IN/SEC)	$P_{c\,max}$ (PSIA)	$\bar{P}_c$ (PSIA)	$\int_{t_i}^{t_f} Pdt$ (PSIA)	Fmax (lb)	$\bar{F}$ (lb)	Cd	It (lb-SEC)	Isp (SEC)	C* (FT/SEC)	W		P_c (AT Fmax) (PSIA)			
0.315	693	590	21970	59760	51800	0.942	1,919,000	**230.3	**52[illegible]	7416		651			
				*457	*386		*14,240								

REMARKS: THIOKOL CHEMICAL CORP. STANDARD DEFINITIONS ARE APPLIED TO PARAMETERS OUTLINED BY HEAVY BLACK BOUNDRY. DATA TAKEN FROM "A" BRIDGE.

** Wp USED TO CALCULATE C* & Isp. * PRE-LOAD CORRECTION VALUES Added TO THRUST PARAMETERS.

NOTE: CAVITY TEMPERATURE AT TIME OF FIRING 72°F, PRELOAD ANGLE = COS 0°

*** NOTE: All Ignition Times Taken From High Frequency Oscillograph Trace.

Figure 81. Data Summary of TX354 Motor 1 from Mixes B-2007, B-2008, and B-2014.

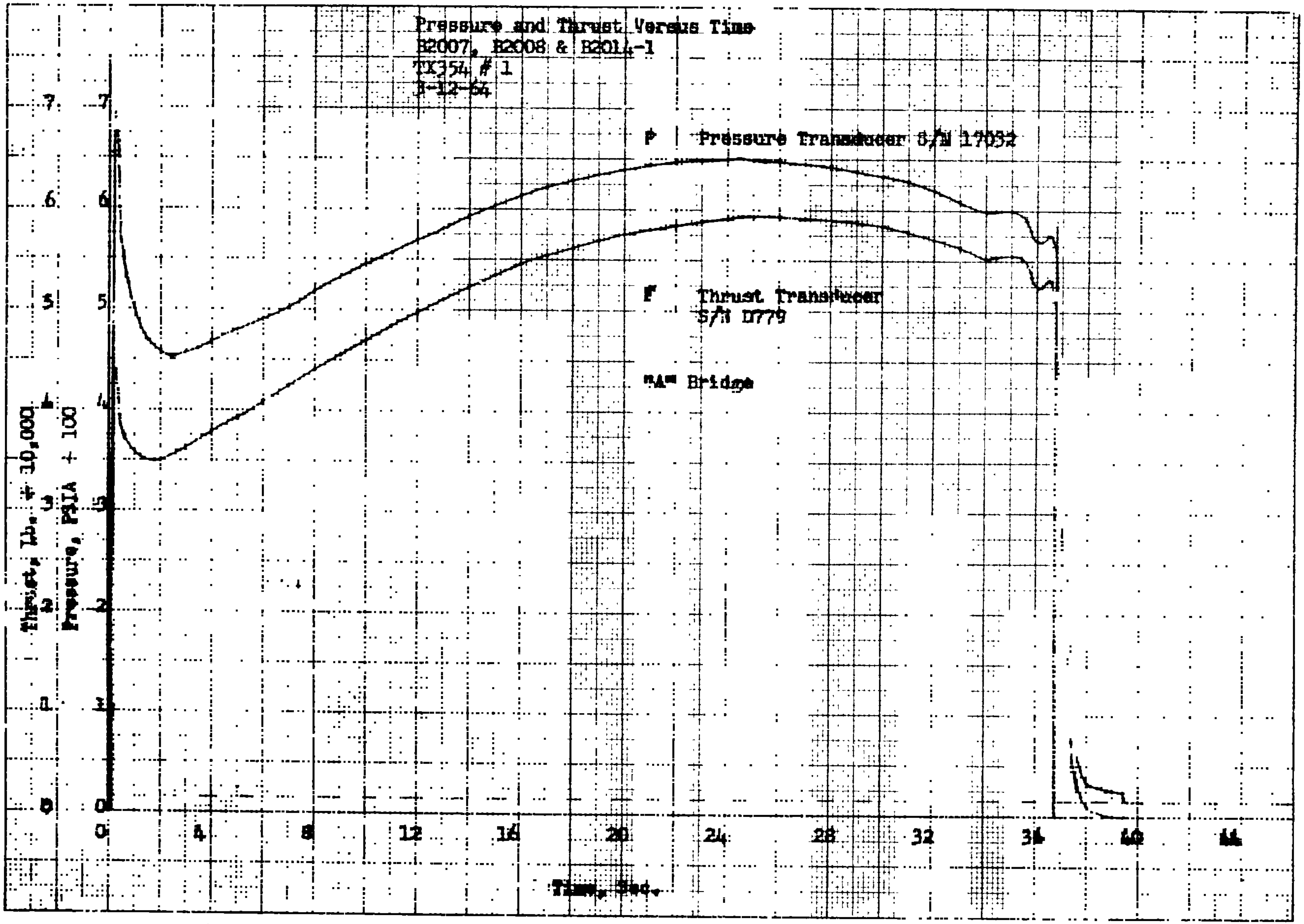


Figure 82. Pressure and Thrust versus Time of TX354 Motor 1.

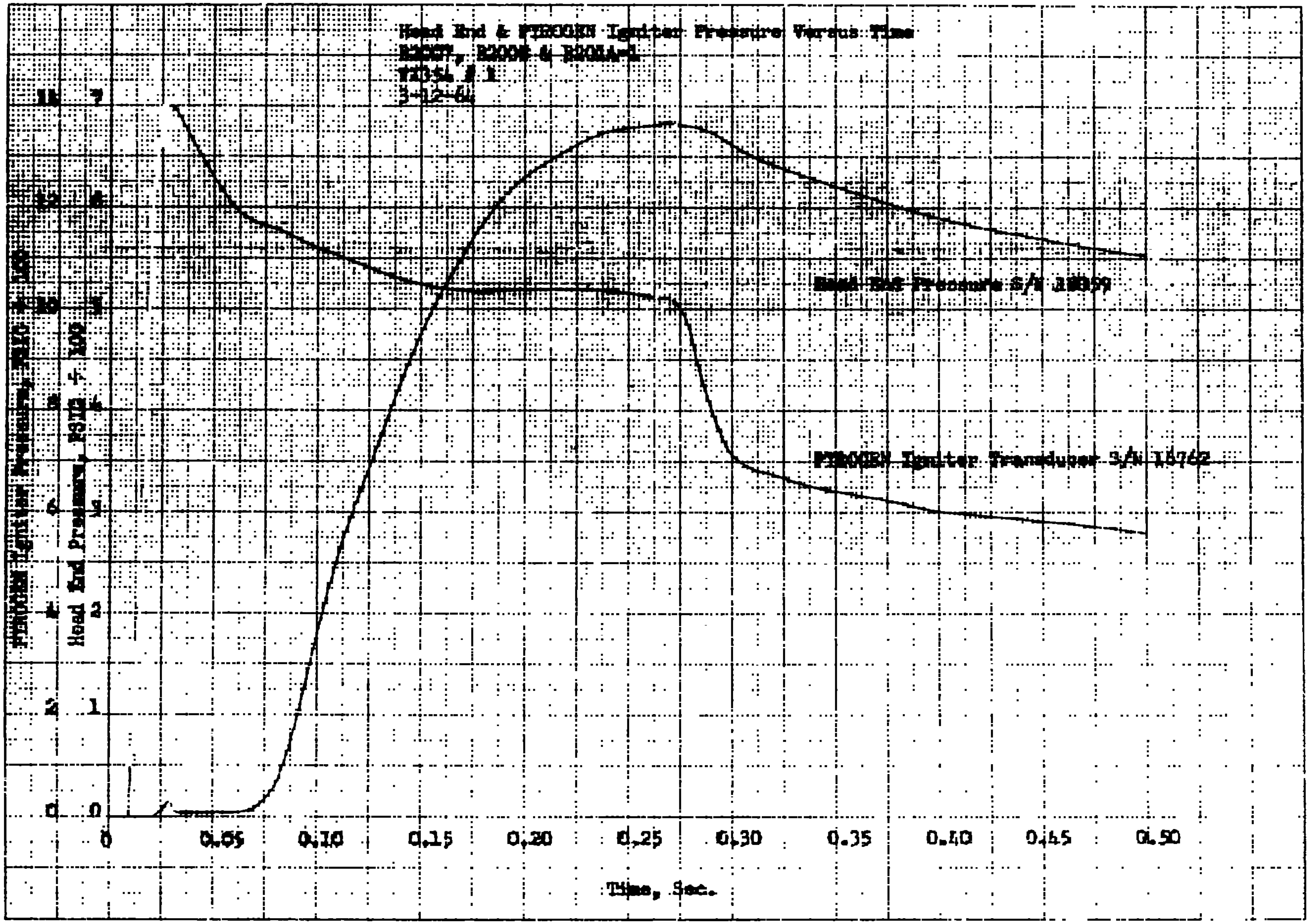


Figure 83. Head-End and Pyrogen Igniter Pressure versus Time of TX354 Motor 1.

B2083/B2084/B2085

MOTOR DATA SUMMARY

CHG NO	MOTOR TYPE	PROGRAM	PROPELLANT TYPE	DATE FIRED	DATE CAST	Wp (LB)	Wb (LB)	% PROPELLANT RESIDUE	TEMPERATURE (°F) GRAIN	AMB	BAR PRESS IN "Hg"	% R H
1	[redacted]	CASTOR II	TP-H7031	7-7-64	4-15-64	8364.6			75	64	[illegible]	64
	TX354 #3											

NOZZLE DIA (IN) BEFORE	AFTER	A_t (IN²)	ΔA_t (IN²)	A_e/A_t	$A_e/\bar{A}_t$	1/2 ∠	IGNITER	$t_{c50\%}$ (SEC)	$t_{50\%\text{-web}}$ (SEC)	t_{apr-o} (SEC)	$\bar{P}$ web (PSIA)	$P_{50\%\text{-web}}$ (PSIA)
8.756 8.755	9.043 9.043	62.214	+4.026	10.435	10.116	22.4°	TX[illegible] J2634-10 SN 21	0.178	36.35[illegible]	37.5[illegible]	[illegible]	[illegible]
8.755	9.044											

$\int Pdt_1$ (PSIA-SEC)	$\int Pdt_2$ (PSIA-SEC)	C* (FT/SEC)	F_{max} (LB)	$F_{50\%\text{-web}}$ (LB)	I (LB-SEC)	I_{sp} (SEC)	r (IN/SEC)	C_f	C_d	t_{id} (SEC)	t_i 10% (SEC)	t_i 70% (SEC)	t_i 90% (SEC)	t_b (SEC)	t_f (SEC)
21180	21860	5231	59500	50860	1904000	227.6	0.319	1.402	0.952	0.126	***[illegible]	***3.[illegible]	***[illegible]	[illegible]6.404	[illegible]
			*492	*444	*16277										

$\bar{r}$ (IN/SEC)	$P_{c\,max}$ (PSIA)	P_c (PSIA)	$\int_{t_0}^{t_f} Pdt$ (PSIA)	F_{max} (lb)	$\bar{F}$ (lb)	Cd	It (lb-SEC)	Isp (SEC)	C* (FT/SEC)	W		P_c (AT F_{max}) (PSIA)			
0.318	644	582	21360	575[illegible]	50820	0.953	1904000	**[illegible]	**[illegible]	[illegible]		644			
				*492	*443		*16277								

	NOTE:	MOTOR	Chamber	PRESSURE	Evacuated										
		TO	0.150	Mm Hg.	@	IGNITION									

REMARKS THIOKOL ~~CHEMICAL~~ CORP STANDARD DEFINITIONS ARE APPLIED TO PARAMETERS OUTLINED BY HEAVY BLACK BOUNDRY DATA TAKEN [illegible]

** Wp USED TO CALCULATE C* & Isp. *PRE-LOAD CORRECTION VALUES Added To THRUST PARAMETERS.

NOTE: CAVITY TEMPERATURE AT TIME OF FIRING 76 °F, PRE LOAD ANGLE = [illegible]°

Div.-42-560(7-59) NOTE: *** ALL IGNITION TIMES TAKEN FROM HIGH FREQUENCY [illegible] GRAPH TRACE, And IN Reference To IGNITION Peak PRESSURE.

Figure 84. Data Summary of TX354 Motor 3 from Mixes B-2083, B-2084 and B-2085.

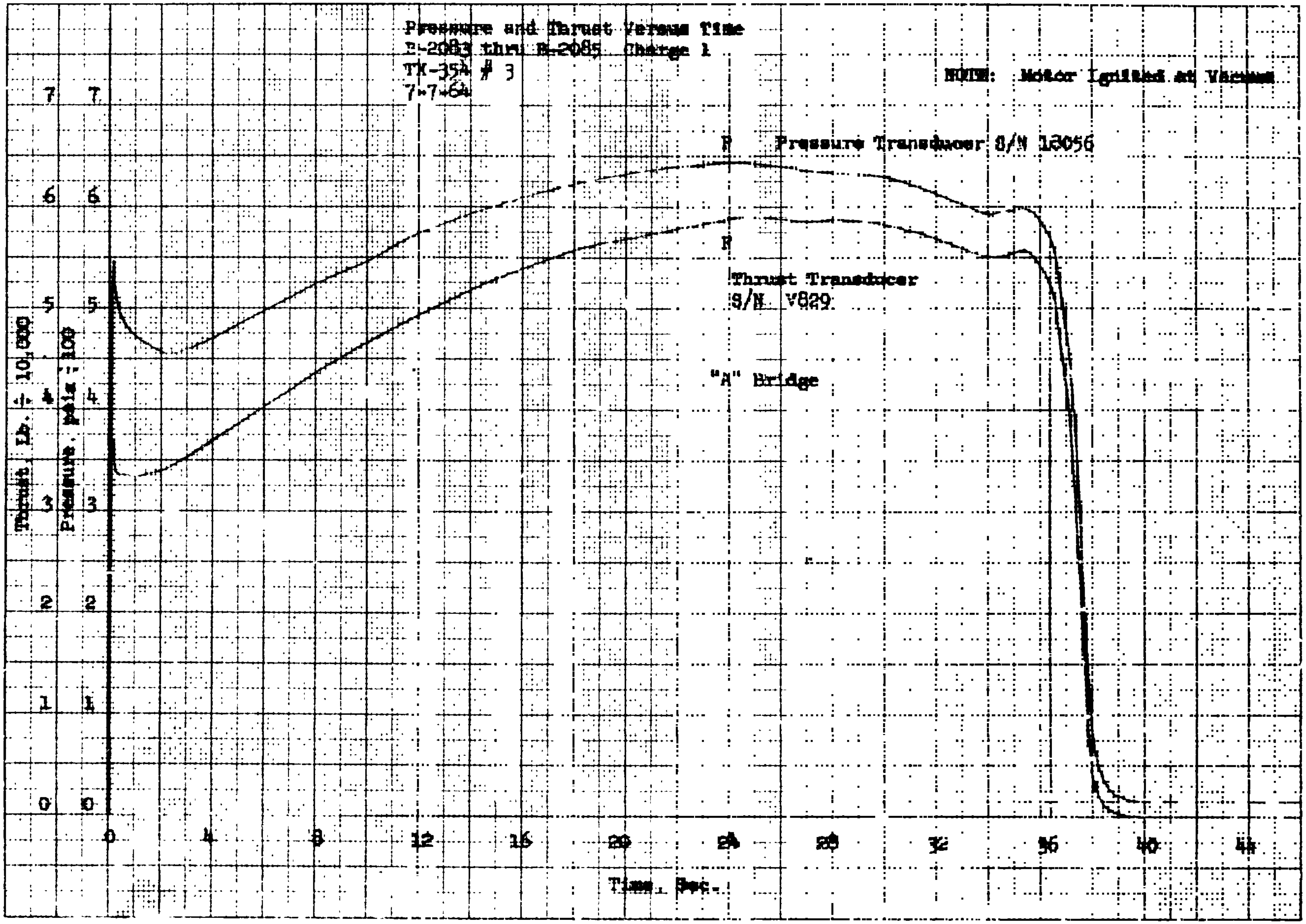


Figure 85. Pressure and Thrust versus Time of TX354 Motor 3.

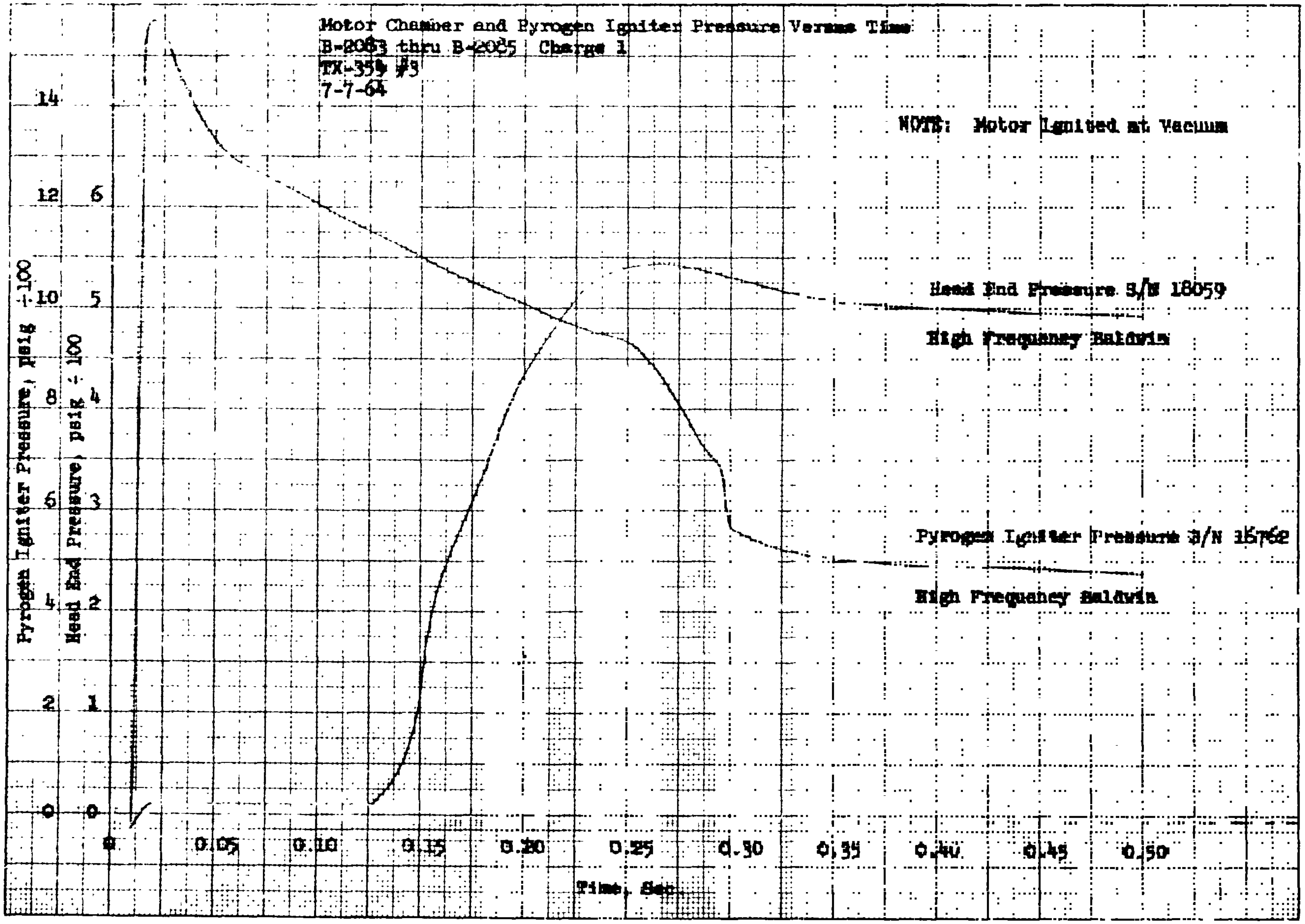


Figure 86. Motor Chamber and Pyrogen Igniter Pressure versus Time of TX354 Motor 3.

CHG NO	MOTOR TYPE	PROGRAM	PROPELLANT TYPE	DATE FIRED	DATE CAST	W_p (LB)	W_b (LB)	% PROPELLANT RESIDUE	TEMPERATURE (°F) GRAIN	TEMPERATURE (°F) AMB	BAR PRESS IN "Hg"	% RH
1	[redacted]- TX 354 #4	510-02-13	TPH-7025	12-5-64	8-6-64	8210.65			75	37	29.30	69

NOZZLE DIA (IN) BEFORE	NOZZLE DIA (IN) AFTER	$\bar{A}_t$ (IN²)	ΔA_t (IN²)	A_e/A_t	$A_e/\bar{A}_t$	1/2 ∠	IGNITER	$t_{d50\%}$ (SEC)	$t_{50\%-web}$ (SEC)	t_{ign-e} (SEC)	P_{max} (PSIA)	$P_{50\%-web}$ (PSIA)
8.292 8.292 8.297	8.516 8.522 8.512	55.493	2.931	***7.116	***6.928	***22.6°	J2690-9 S/N 31	0.111	35.305	37.460	752	667

$\int P dt_1$ (PSIA-SEC)	$\int P dt_2$ (PSIA-SEC)	C* (FT/SEC)	F_{max} (LB)	$F_{50\%-web}$ (LB)	I (LB-SEC)	I_{sp} (SEC)	r (IN/SEC)	C_f	C_d	t_{id} (SEC)	$t_{i\,10\%}$ (SEC)	$t_{i\,70\%}$ (SEC)	$t_{i\,90\%}$ (SEC)	t_b (SEC)	t_f (SEC)
23550	23860	5158								0.018	0.070	0.110	0.131	35400	37.460

r (in/sec)	$P_{c\,max}$ (PSIA)	P_c (PSIA)	$\int_{t_0}^{t_f} P\,dt$ (PSIA)	F_{max} (lb)	$\bar{F}$ (lb)	Cd	I_t (lb-sec)	I_{sp} (SEC)	C* (FT/SEC)	W		P (AT t_f) (PSIA)			
0.327	752	666	23860	*	*	*	*	*	** 5192	*		*			

REMARKS: THIOKOL CHEMICAL CORP STANDARD DEFINITIONS ARE APPLIED TO PARAMETERS OUTLINED BY HEAVY BLACK BOUNDRY. DATA TAKEN FROM "A" BRIDGE

*NOTE: THRUST WAS NOT RECORDED.

** Wp USED TO CALCULATE C*

Figure 87. Data Summary of 1X354 Motor 4.

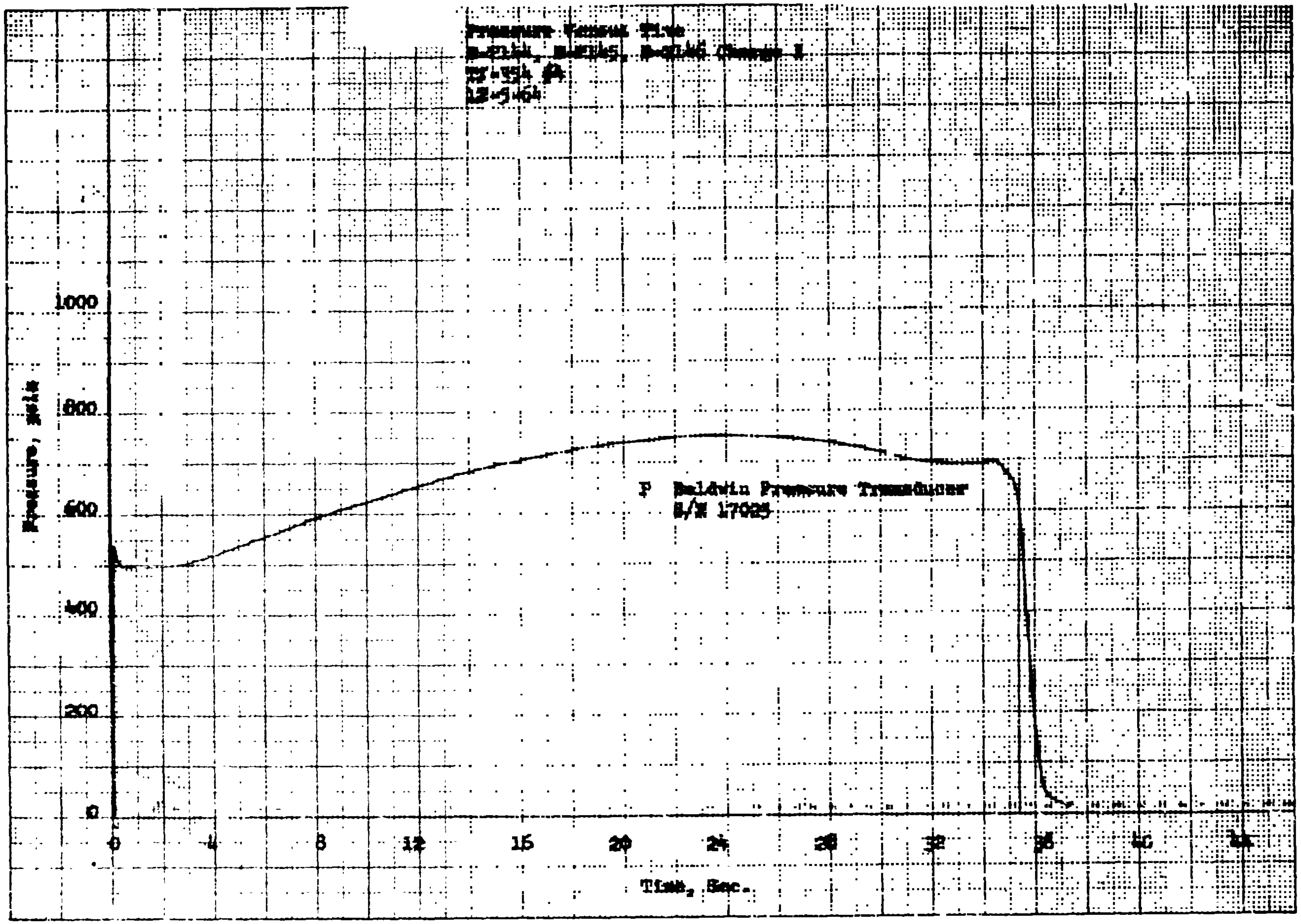


Figure 88. Pressure versus Time of TX354 Motor 4.

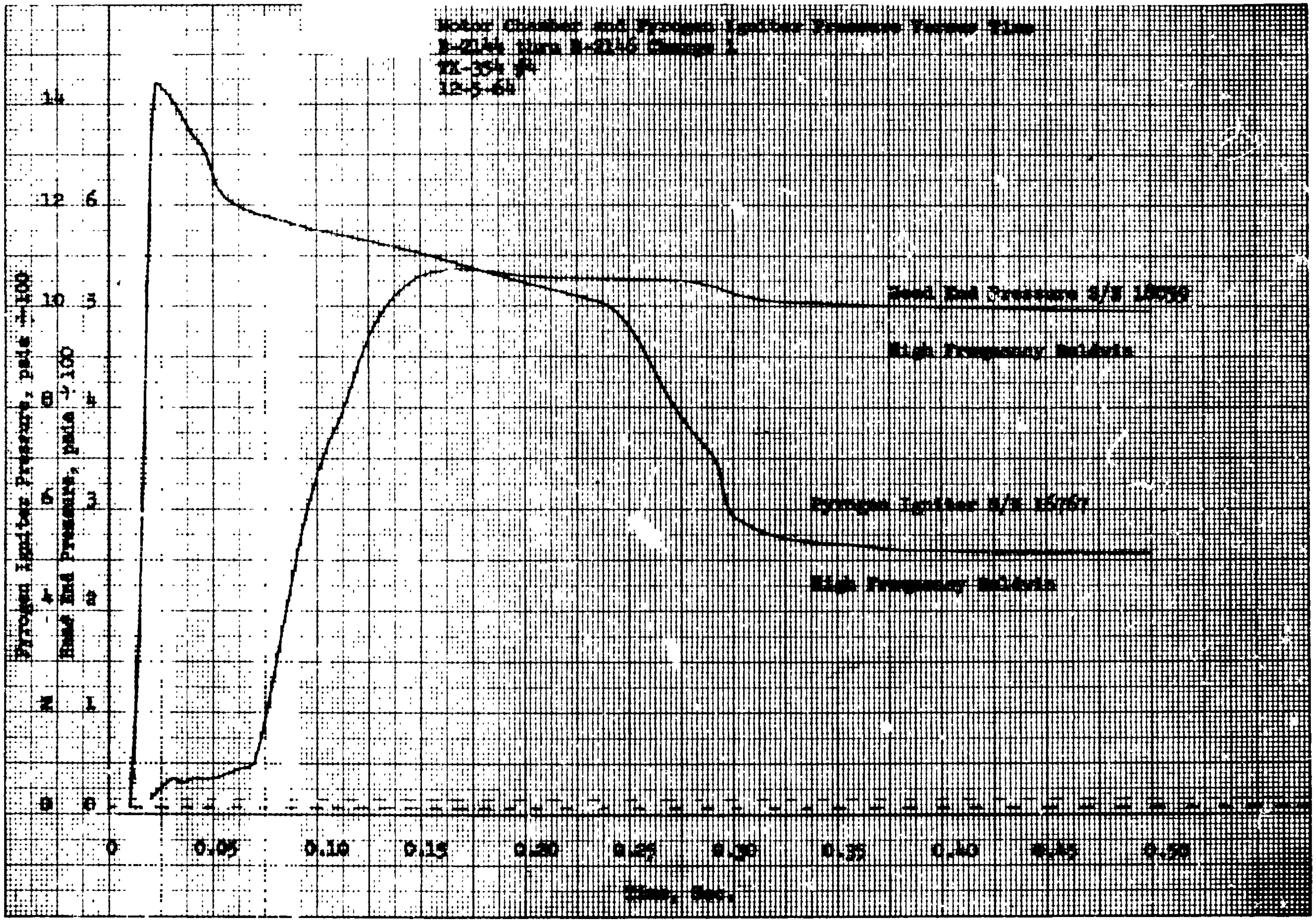


Figure 89. Motor Chamber and Pyrogen Igniter Pressure versus Time of TX354 Motor 4.

B2107 THRU B2109

CHG NO	MOTOR TYPE	PROGRAM	PROPELLANT TYPE	DATE FIRED	DATE CAST	W_p (LB)	W_L (LB)	% PROPELLANT RESIDUE	TEMPERATURE (°F) GRAIN	AMB	BAR PRESS/IN "Hg"	% R H
1	[redacted]	ATHENA	TP-H7021	7-16-64		8349.68			70**	78	30.20	63
	TX354 #8											

NOZZLE DIA (IN) BEFORE	AFTER	$\bar{A}_t$ (IN²)	ΔA_t (IN²)	A_e/A_t	$A_e/\bar{A}_t$	1/2 ∠	IGNITER	$t_{d50\%}$ (SEC)	$t_{50\%\text{-web}}$ (SEC)	t_{apr-o} (SEC)	P max (PSIA)	$P_{50\%\text{-web}}$ (PSIA)
8.752	9.021											
8.751	9.020	62.009	3.698	6.870	6.665	16°22.5'	J2689-4, TX362 #15	0.148	35.313	38.100	828	608
8.752	9.011											

CONTRACT DEFINITIONS PER NASA

$\int P dt_1$ (PSIA-SEC)	$\int P dt_2$ (PSIA-SEC)	C* (FT/SEC)	F_{max} (LB)	$F_{50\%\text{-web}}$ (LB)	I (LB-SEC)	I_{sp} (SEC)	$\bar{r}$ (IN/SEC)	C_f	C_d	t_{id} SEC	t_i 10% SEC	t_i 70% SEC	t_i 90% SEC	t_b SEC	t_f SEC
21460	22110	5287	60950	54180	1973000	236.3	0.328	1.437	0.936	0.060	0.092	1.195	0.330	35.400	38.100
			*431	*374	*13377										

$\bar{r}$ IN/SEC	$P_{c\,MAX}$ PSIA	$\bar{P}_c$ PSIA	$\int P_c dt$ PSIA-SEC	F_{MAX} LB	$\bar{F}$ LB	I_t LB-SEC	I_{sp} SEC	C* FT/SEC	W	Cd					
0.327	828	607	22110	60950	54130	1973000	236.3	5287	7609	0.937					
				*431	*374	*13377									

PER. AIR FORCE LETTER

t_a SEC	t_b SEC	$\bar{P}_a$ PSIA	$\bar{P}_b$ PSIA	$\bar{F}_a$ LB	$I_{t,SL}$	$C_{F,TEST}$	$I_{SP,SL}$	$\bar{F}_{a,VAC}$	$I_{t,VAC}$	$I_{SP,VAC}$					
36.720	35.370	601	607	53620	1969000	1.439	235.8	59750	2194000	262.8					
				*365	*13380										

REMARKS: THIOKOL CHEMICAL CORP. STANDARD DEFINITIONS ARE APPLIED TO PARAMETERS OUTLINED BY HEAVY BLACK BOUNDRY.

*PRELOAD ADDED TO ALL THRUST PARAMETERS. PRELOAD ANGLE COS 0°. DATA TAKEN FROM "A" BRIDGE.

** GRAIN CAVITY AT TIME OF TESTING 74°F

Figure 90. Data Summary of TX-354 Motor 8 from Mixes B-2107 through B-2109.

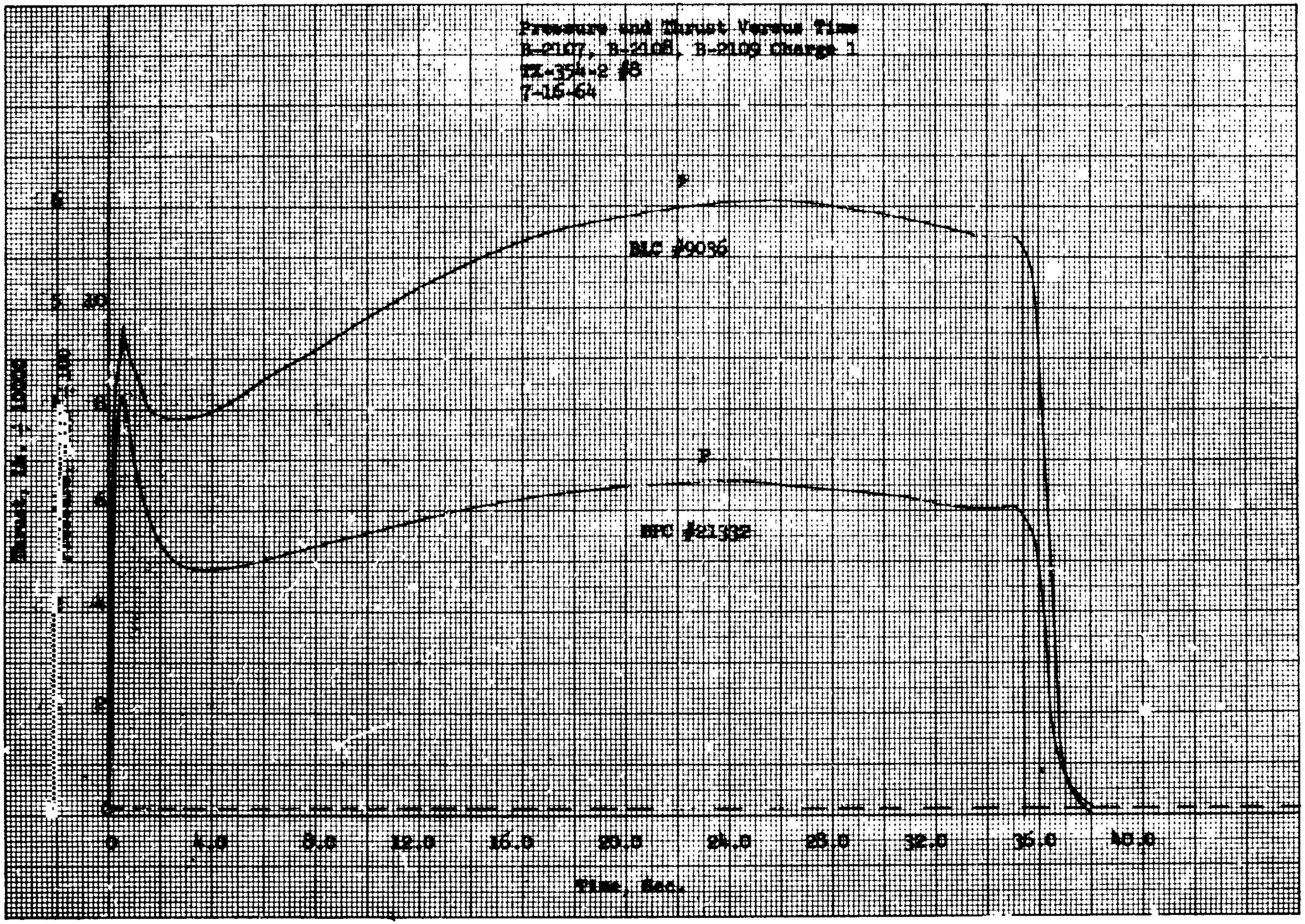


Figure 91. Pressure and Thrust versus Time of TX354 Motor 8.

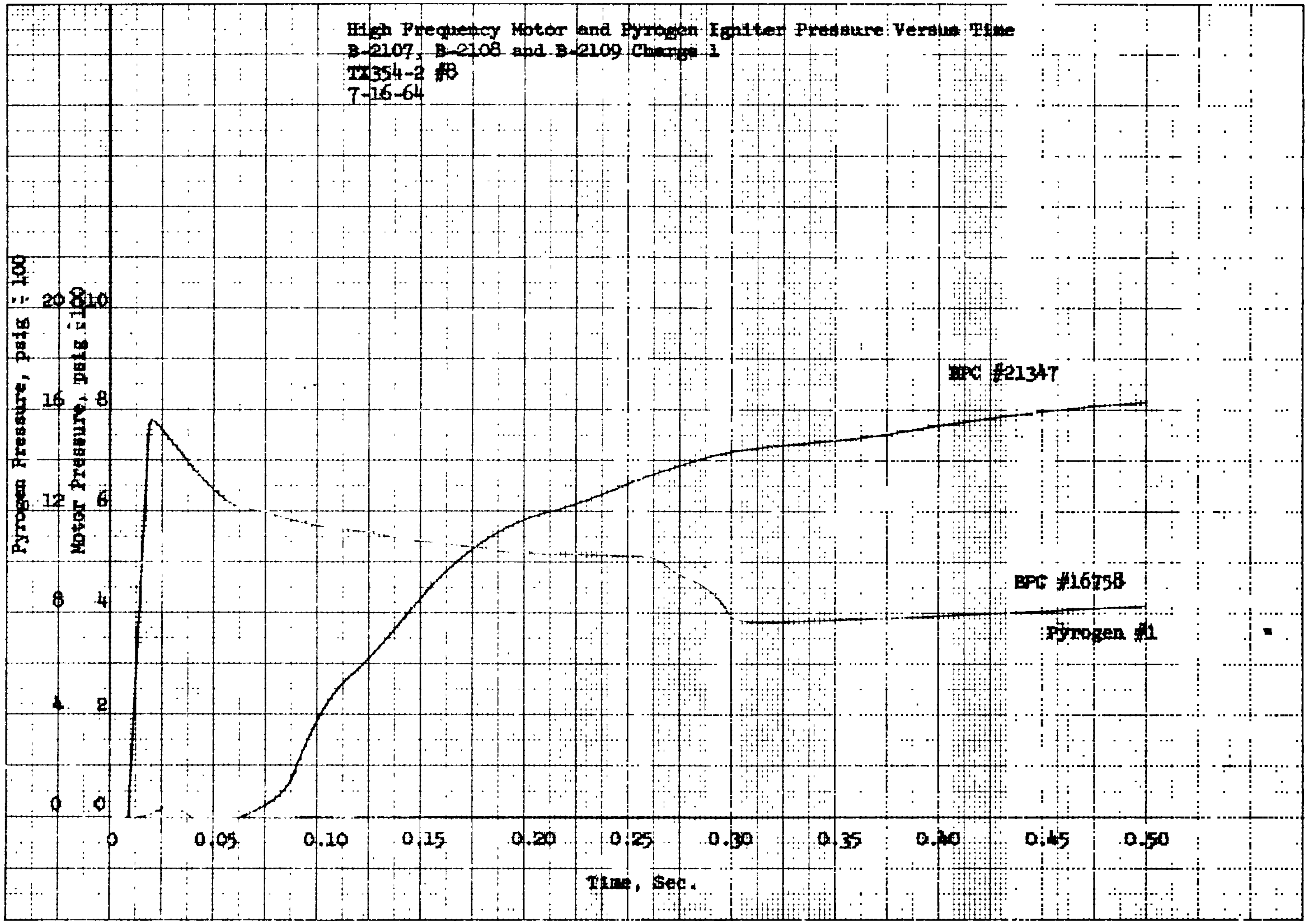


Figure 92. High Frequency Motor and Pyrogen Igniter Pressure versus Time of TX354 Motor 8.

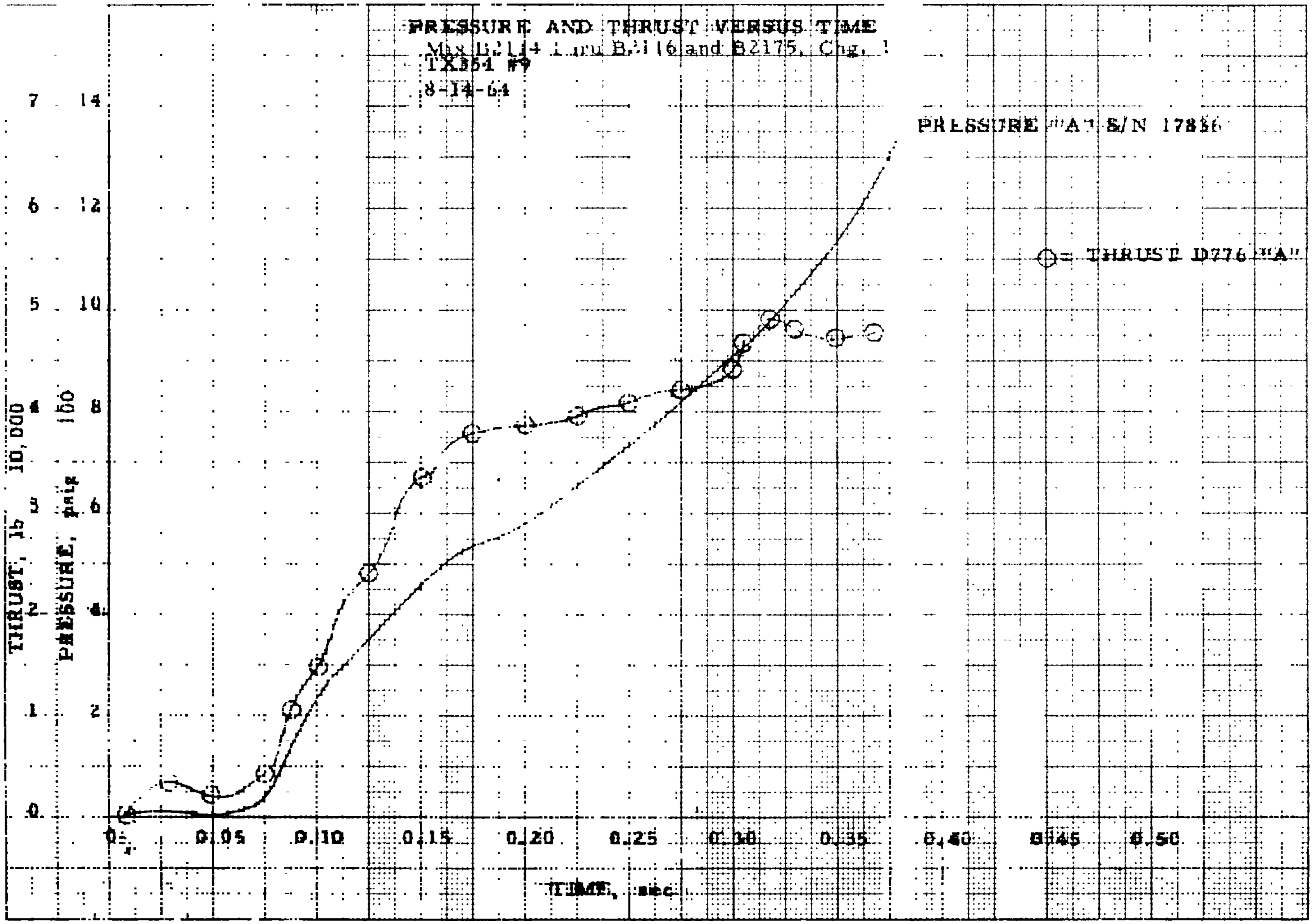


Figure 93. Pressure and Thrust versus Time of TX354 Motor 9.

NO B2193 THRU B2195 & B2197

CHG NO	MOTOR TYPE	PROGRAM	PROPELLANT TYPE	DATE FIRED	DATE CAST	Wp (LB)	Wb (LB)	% PROPELLANT RESIDUE	TEMPERATURE (°F)		BAR PRESS /N "Hg"	% R H
									GRAIN	AMB		
1	[redacted]-	503-11-13	TPH-[illegible]025	4-24-64	[illegible]-21-64	8[illegible]25.3			*70	76	29.70	34
	TX354-2 #11											

NOZZLE DIA (IN)		$\bar{A}_t$ (IN²)	ΔA_t (IN²)	A_e/A_t	$A_e/\bar{A}_t$	1/2 ∠	IGNITER	$t_{d50\%}$ (SEC)	$t_{50\%\text{-web}}$ (SEC)	$t_{apr\text{-}o}$ (SEC)	P max (PSIA)	$P_{50\%\text{-web}}$ (PSIA)
BEFORE	AFTER											
8.293 8.273 8.291	8.535 8.557 8.520	55.621	3.233	7.665	7.445	16[illegible]	TX36[illegible] SN 2[illegible] J2684-9	0.199	37.153	40.200	703	627

CONTRACT DEFINITIONS PER NASA -

$\int P dt_1$ (PSIA-SEC)	$\int P dt_2$ (PSIA-SEC)	C* (FT/SEC)	Fmax (LB)	F50%-web (LB)	I (LB-SEC)	Isp (SEC)	r (IN/SEC)	Cf	Cd	t_{ig} (SEC)	t, 10% (SEC)	t, [illegible]% (SEC)	t, 90% (SEC)	t_b (SEC)	t_f (SEC)
23290	23970	5213	60510	51490	1967000	239.1	0.31[illegible]	1.4[illegible]	0.[illegible]	0.15[illegible]	***0.158	***0.192	***0.215	37.200	40.200
			**2[illegible]1	**225	**5584										

[illegible]

r (in/SEC)	$P_{c\,max}$ (psia)	$\bar{P}_c$ (psia)	$\int P_c dt$ (psia-sec)	F_{max} (lb)	$\bar{F}$ (lb)	I_t (lb-sec)	I_{sp} (sec)	C* (ft/sec)	W	Cd
0.311	70[illegible]	6[illegible]6	23170	60510	51450	1967000	239.1	****5[illegible]7	7674	0.760
				**251	**235	**5584				

PER AIR FORCE LETTER

t_c (SEC)	t_b (SEC)	$\bar{P}_a$ (psia)	$\bar{P}_b$ (psia)	$\bar{F}_a$ (lb)	$I_{t,SL}$	C_F, Test	$I_{sp,SL}$	$\bar{F}$ vac	$I_{t,vac}$	$I_{sp,vac}$
38.231	37.519	[illegible]	[illegible]	5[illegible]	1965000	1.477	****235.[illegible]	5[illegible]	[illegible]	****2[illegible]7.1
				**[illegible]6	**6723					

REMARKS THIOKOL CHEMICAL CORP STANDARD DEFINITIONS ARE APPLIED TO PARAMETERS OUTLINED BY HEAVY BLACK BOUNDRY * Grain Temp at Time of Testing 77°F

** F[illegible] Load [illegible] Parameters. PRE[illegible] ANGLE [illegible]. DATA TAKEN FROM "A BRIDGE.

*** [illegible] TAKEN FROM [illegible] Pmax. **** [illegible] USED TO CALCULATE [illegible] IN CONTRACT DEFINATIONS

Figure 94. Data Summary of TX354-2 Motor 11 from Mixes B-2195 and B-2197.

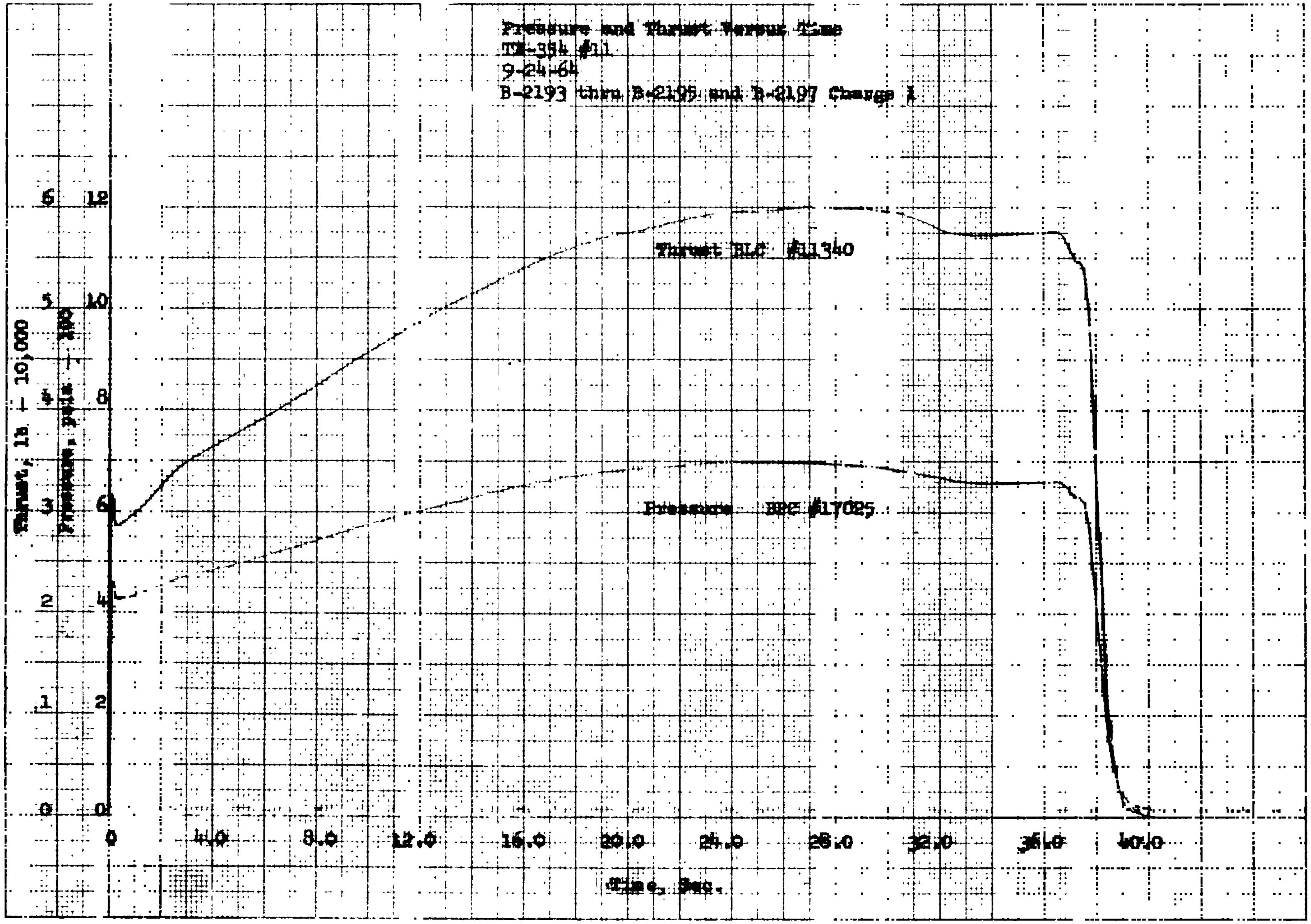


Figure 95. Pressure and Thrust versus Time of TX354 Motor 11.

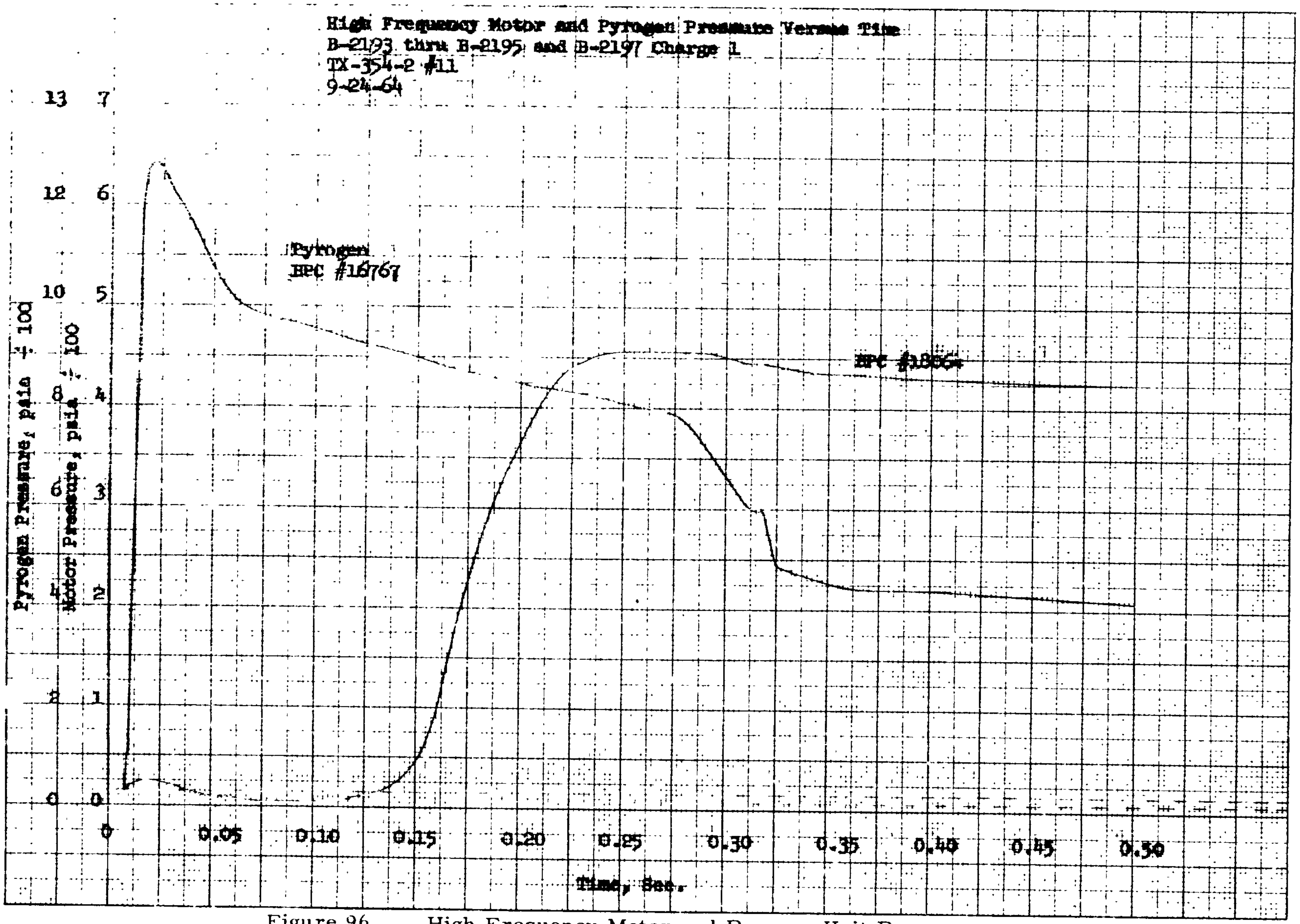


Figure 96. High Frequency Motor and Pyrogen Unit Pressure versus Time of TX354-2 Motor 11.

MIX NO B2193, B2195, B2196 + B2197

CHG NO	MOTOR TYPE	PROGRAM	PROPELLANT TYPE	DATE FIRED	DATE CAST	Wp (LB)	Wb (LB)	% PROPELLANT RESIDUE	TEMPERATURE (°F) GRAIN	TEMPERATURE (°F) AMB	BAR PRESS "Hg"	% R H
2	[redacted]	ATHENA	TP-H7025	10-16-64	7-23-64	8195	*	*	76	69	29.85	49
	TX354 #12											

NOZZLE DIA (IN) BEFORE	NOZZLE DIA (IN) AFTER	$\bar{A}_t$ (IN²)	ΔA_t (IN²)	A_e/A_t	$A_e/\bar{A}_t$	1/2 ∠	IGNITER	td50% (SEC)	t50%-web (SEC)	tapr-o (SEC)	P max (PSIA)	P50%-web (PSIA)
8.289 8.289 8.288	8.303 8.294 8.321	54.074	0.222	7.412	7.397	16°22'5"	J2684-8 S/N 19	0.107	*	*	523	*

$\int P dt_1$ (PSIA-SEC)	$\int P dt_2$ (PSIA-SEC)	C* (FT/SEC)	Fmax (LB)	F50%-web (LB)	I (LB-SEC)	Isp (SEC)	r (IN/SEC)	Cf	Cd
*	*	*	40820 ** 317	*	*	*	*	*	*

CONTRACT DEFINITIONS PER NASA -

t_{id} SEC	t_i 10% SEC	t_i 70% SEC	t_i 90% SEC	t_b (SEC)	t_f (SEC)
0.010	0.082	0.127	0.149	*	*

TX-33 PROGRAM

$\bar{r}$ in/sec	P_c max (PSIA)	$\bar{P}_c$ (PSIA)	$\int_0 P dt$ (PSIA-SEC)	Fmax (lb)	$\bar{F}$ (lb)	I_t (lb-sec)	Isp (sec)	C* FT/sec	W	Cd
*	522	*	*	40820 ** 317	*	*	*	*	*	*

PER AIR FORCE LETTER

t_a (sec)	t_b (sec)	$\bar{P}_a$ (psia)	$\bar{P}_b$ (psia)	$\bar{F}_a$ (lb)	$I_{t,SL}$	C_F Test	$I_{sp,SL}$	$\bar{F}_{a\,vac}$	$I_{t,vac}$	$I_{sp,vac}$
*	*	*	*	*	*	*	*	*	*	*

REMARKS: THIOKOL CHEMICAL CORP. STANDARD DEFINITIONS ARE APPLIED TO PARAMETERS OUTLINED BY HEAVY BLACK BOUNDRY.

* These PARAMETERS NOT available due to burn through

** PRELOAD ANGLE COS 21°56' ADDED TO THRUST MAX.

Figure 97. Data Summary of TX354 Motor 12 from Mixes B-2193, B-2195, B-2196 and B-2197.

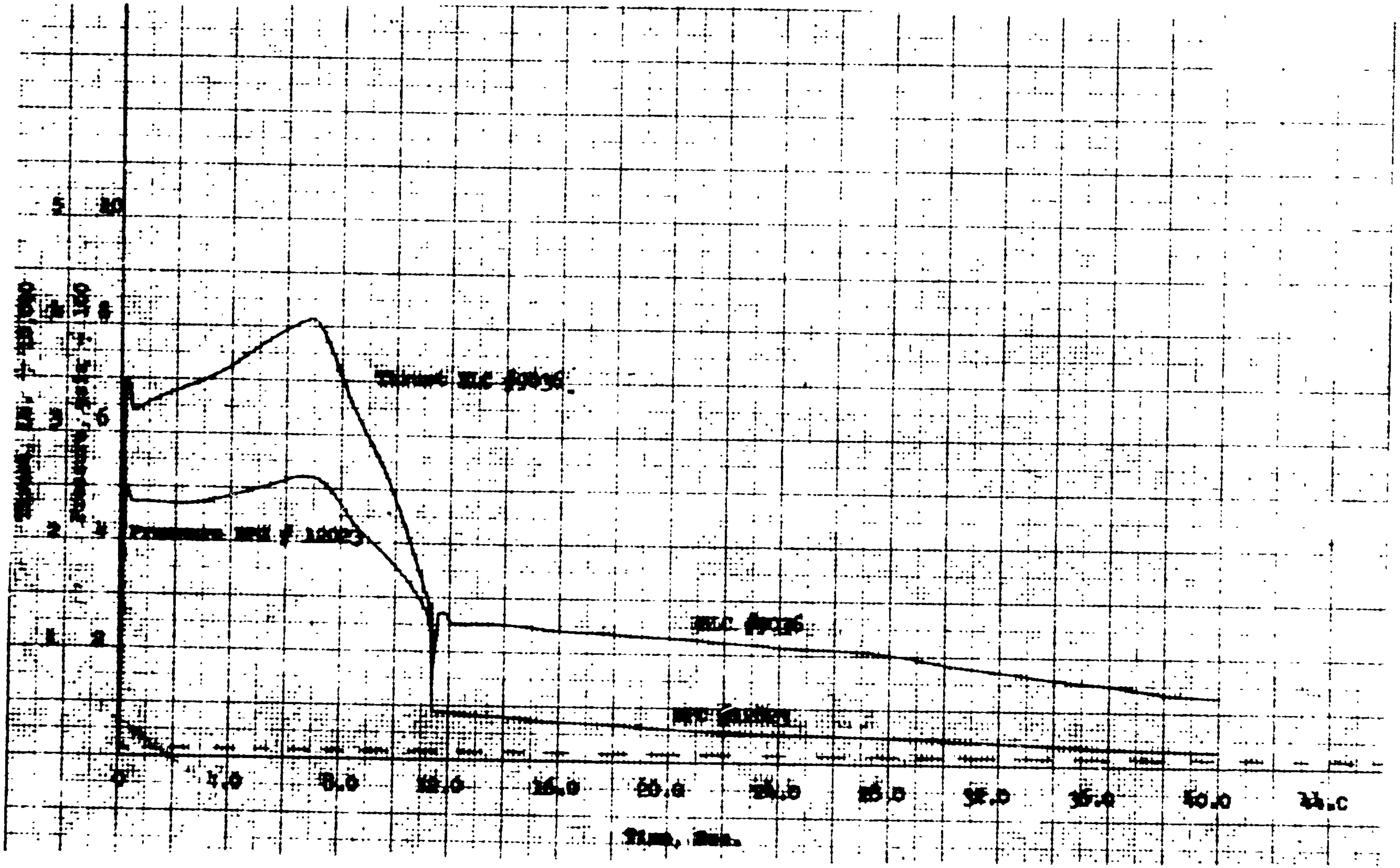


Figure 98. Pressure and Thrust versus Time of TX354 Motor 12.

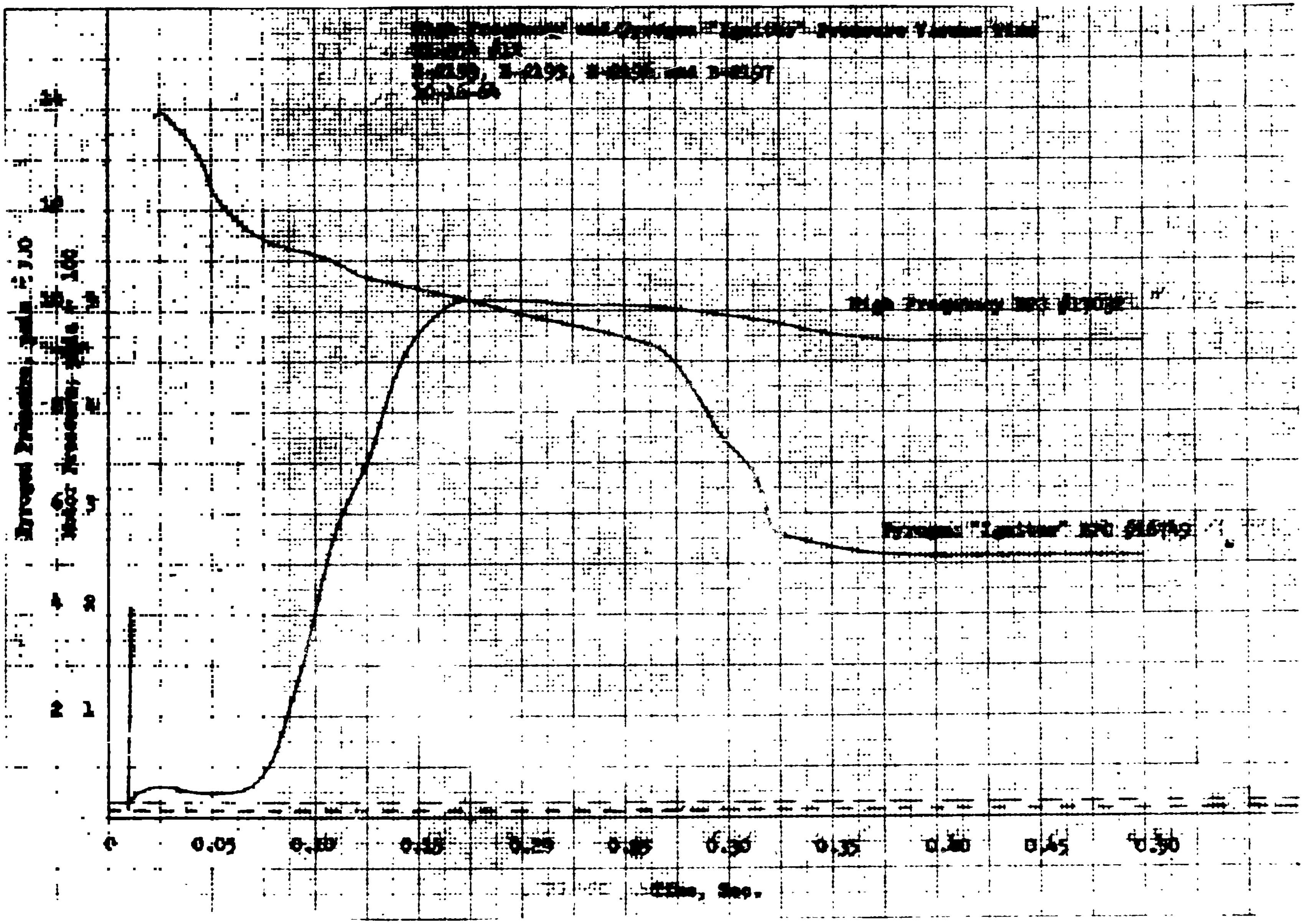


Figure 99. High Frequency and Pyrogen Igniter Pressure versus Time for TX354 Motor 12.

Figure 100. Aft-End of Nozzle After Test Showing Delaminations.

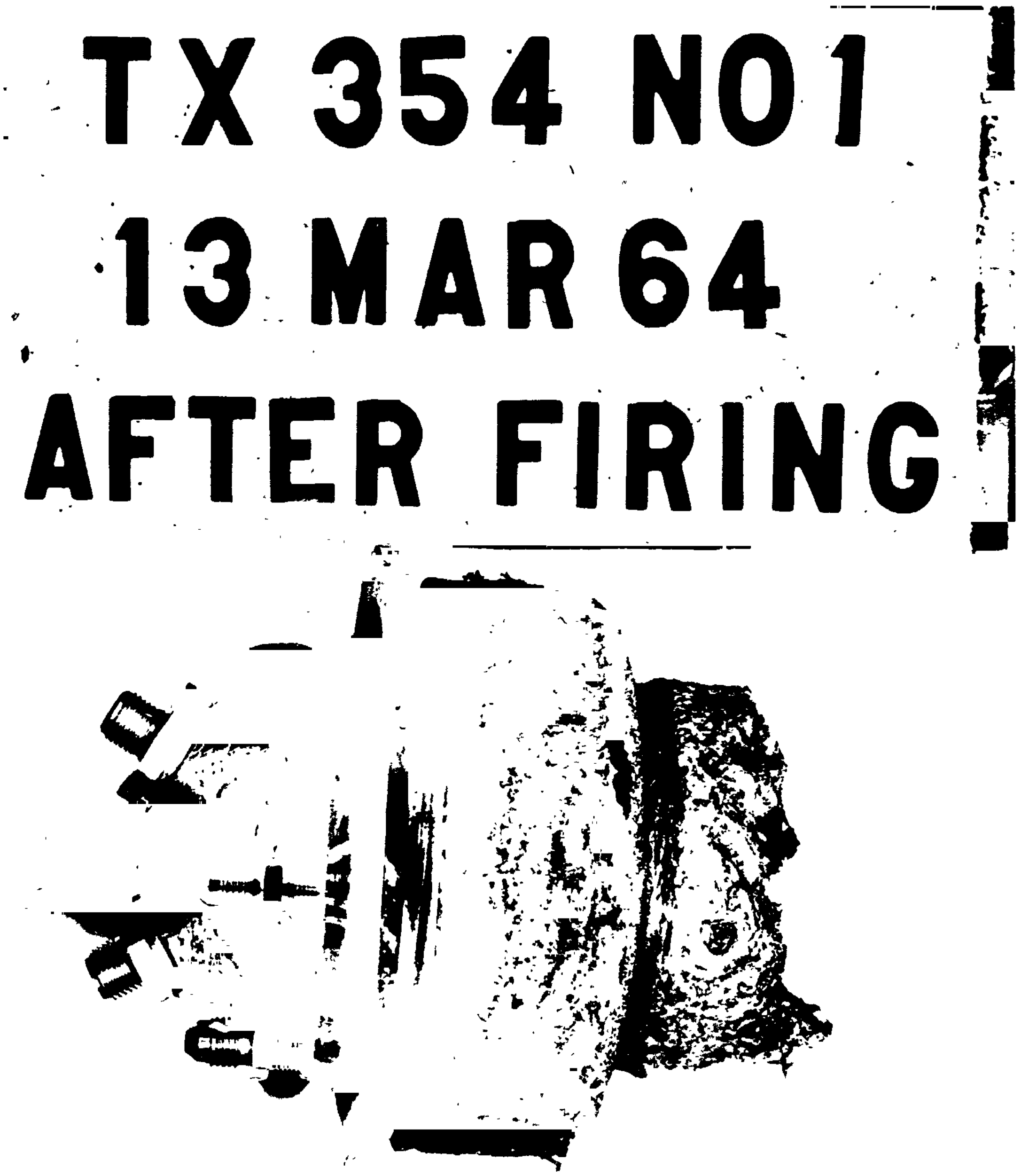


Figure 101. Pyrogen Ignition Case After Test of TX354 Motor 1.

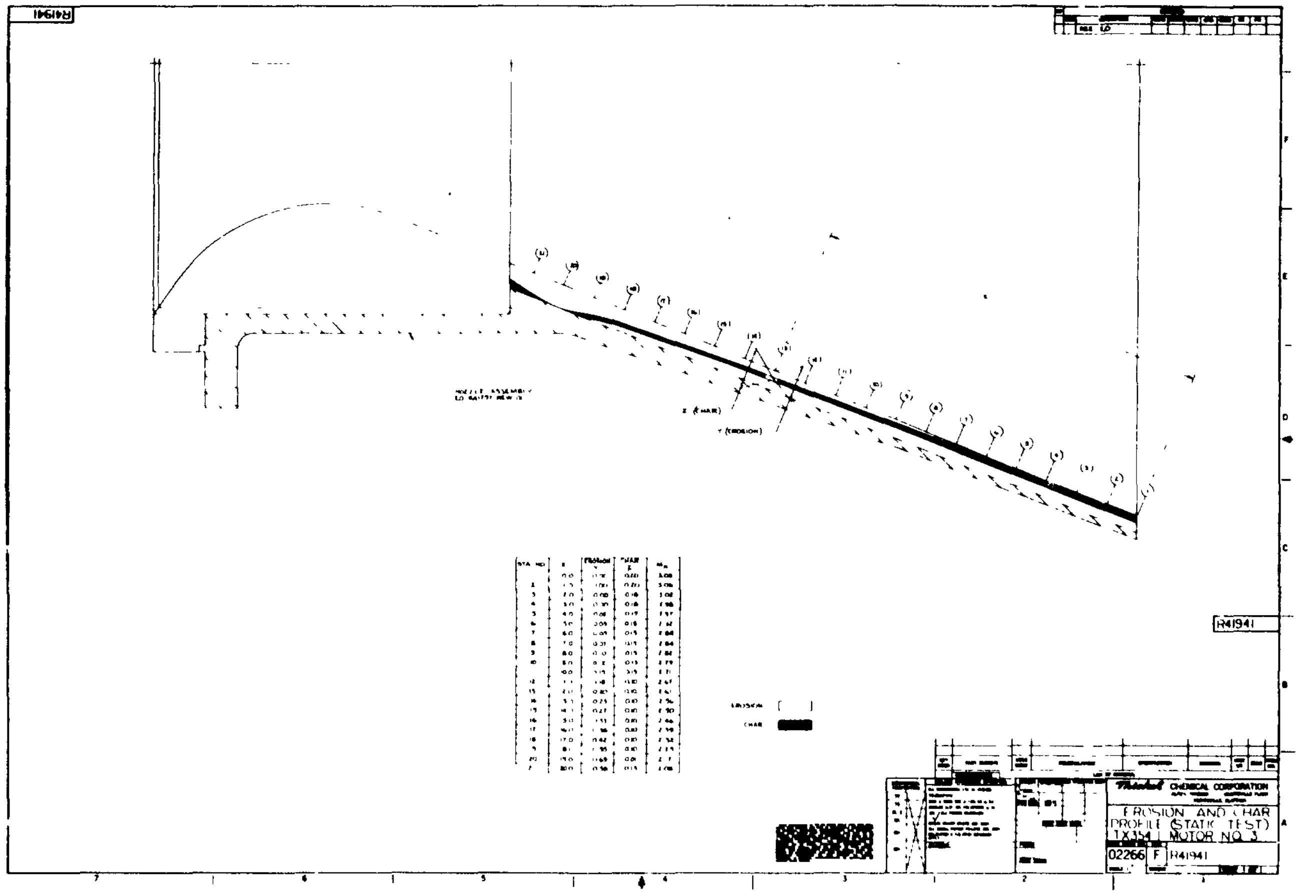
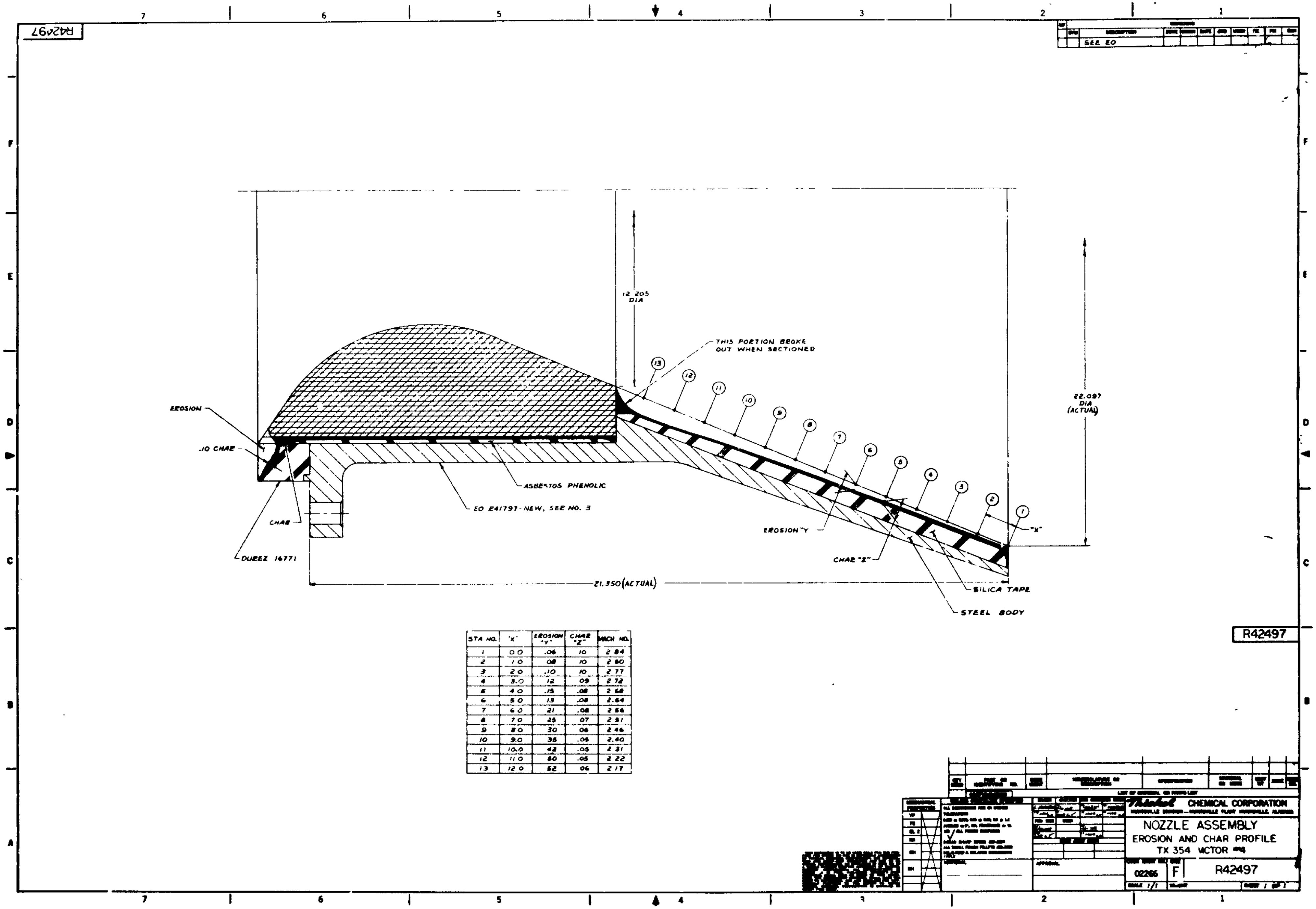


Figure 102. Erosion Profile of Nozzle Used on TX354 Motor 3 During Static Test.



STA NO.	'X'	EROSION "Y"	CHAR "Z"	MACH NO.
1	0 0	.06	10	2 84
2	1 0	08	10	2 80
3	2 0	.10	10	2 77
4	3.0	12	09	2 72
5	4 0	.15	.08	2 68
6	5 0	19	.08	2.64
7	6 0	21	.08	2 56
8	7 0	25	07	2 51
9	8 0	30	06	2 46
10	9.0	35	.06	2.40
11	10.0	42	.05	2 31
12	11 0	50	.05	2 22
13	12 0	52	06	2 17

Figure 103. Erosion Profile of Nozzle Used on TX354 Motor 4 During Static Test.

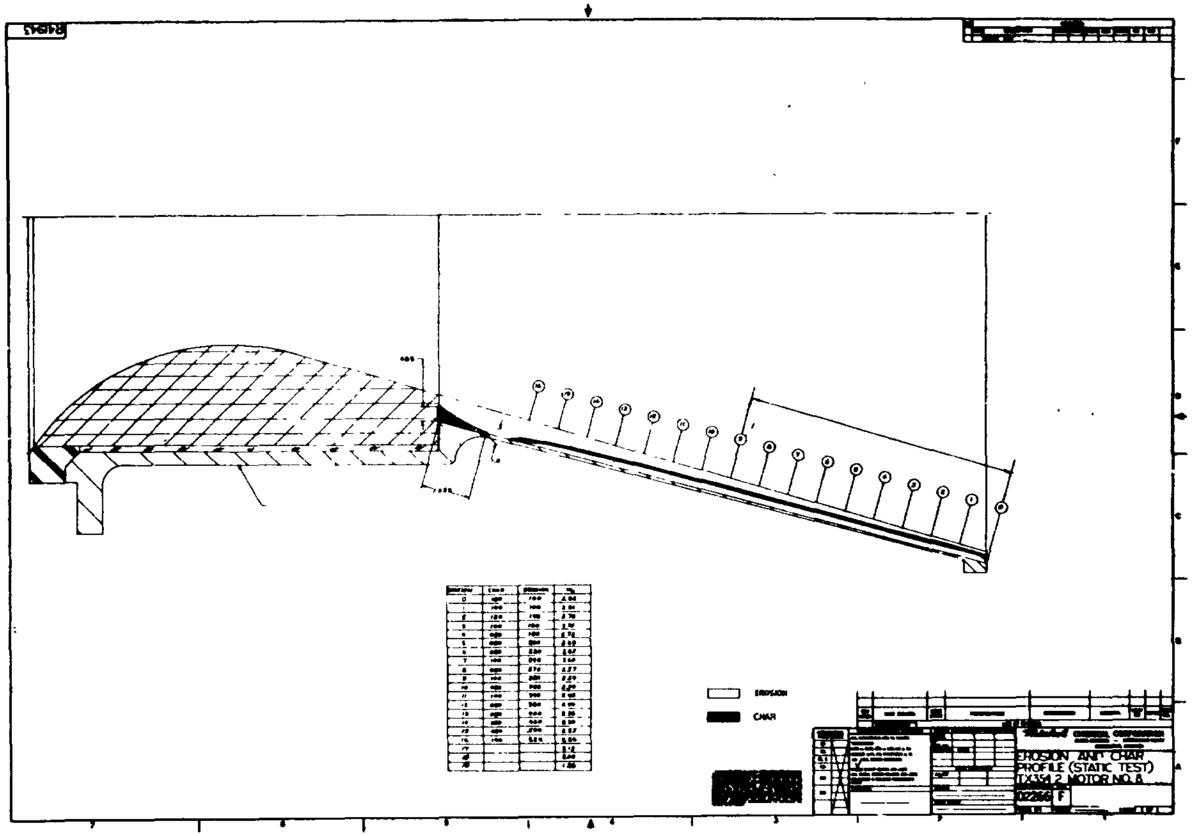


Figure 104. Erosion Profile of Nozzle Used on TX354 Motor 8 During Static Test.

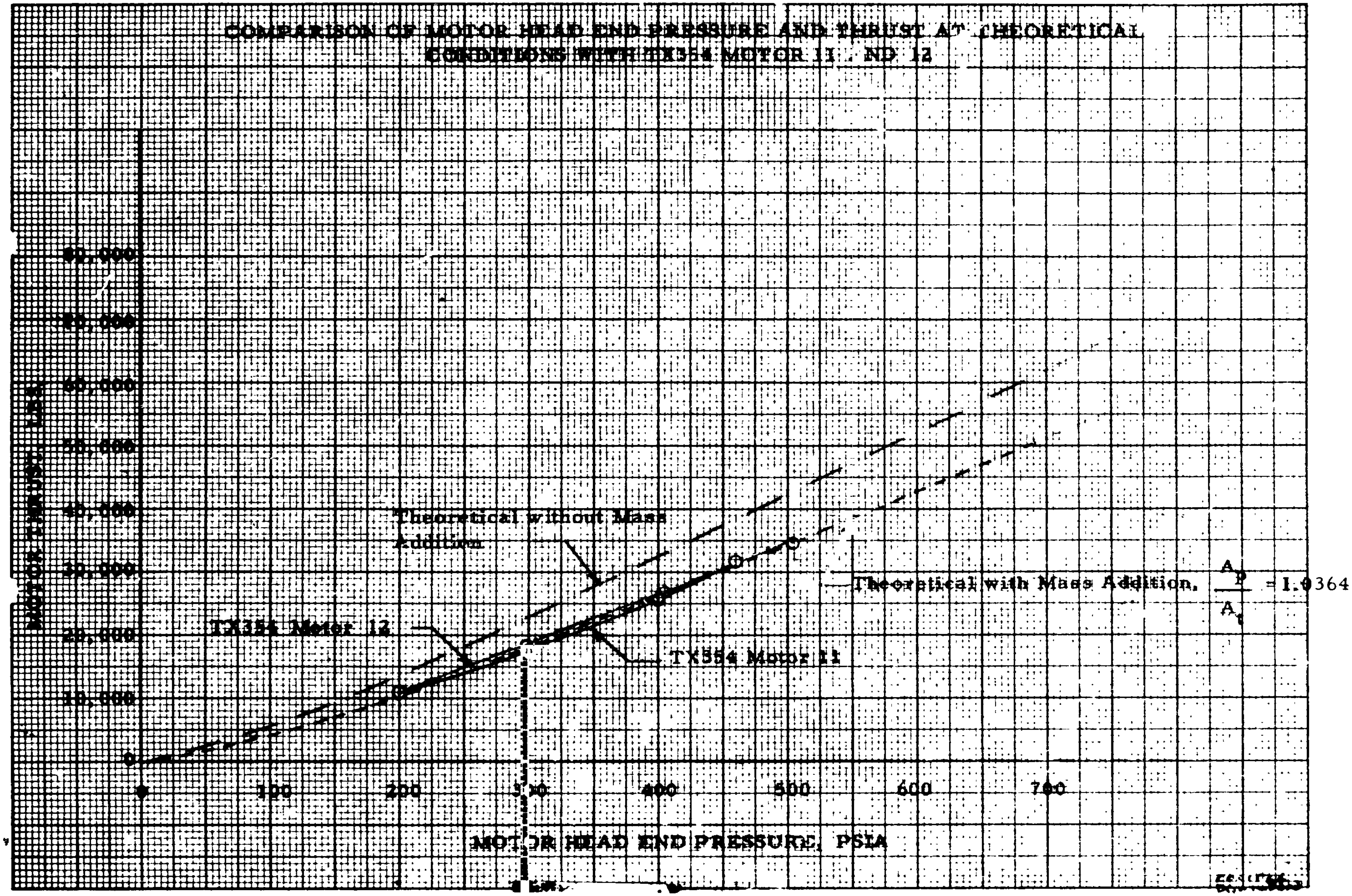


Figure 105. Comparison of Theoretical Head-End Pressure and Thrust With Results Obtained for TX354 Motors 11 and 12.

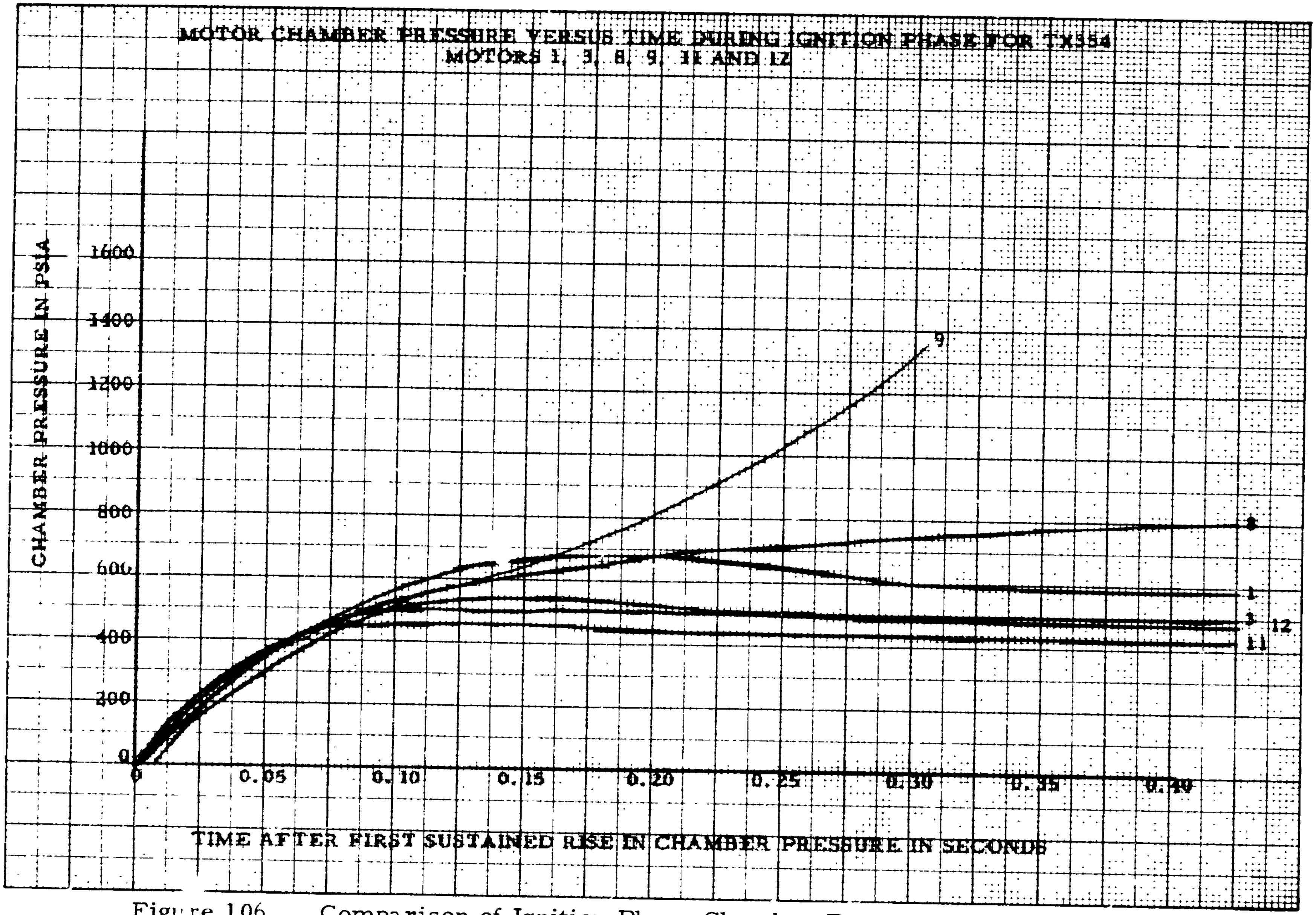


Figure 106. Comparison of Ignition Phase Chamber Pressure versus Time for TX354 Motors 1, 3, 8, 9, 11, and 12.

MIX NO. B2230, 3223, 32232 & B2303

CHG NO	MOTOR TYPE	PROGRAM	PROPELLANT TYPE	DATE FIRED	DATE CAST	Wp (LB)	Wb (LB)	% PROPELLANT RESIDUE	TEMPERATURE (°F) GRAIN	TEMPERATURE (°F) AMB	BAR PRESS "Hg"	% R H
1	[redacted] Tx354#5	CASTOR II	TPH-7025	4-26-65		8203.54				71		

NOZZLE DIA (IN) BEFORE	NOZZLE DIA (IN) AFTER	$\bar{A}_t$ (IN²)	ΔA_t (IN²)	A_e/A_t	$A_e/\bar{A}_t$	1/2 ∠	IGNITER	$t_{a50\%}$ (SEC)	$t_{50\%\text{-web}}$ (SEC)	t_{ap} (SEC)	P_{max} (PSIA)	$\bar{P}_{50\%\text{-web}}$ (PSIA)
8.289	8.545 8.543 8.520	55.595	3.264	21.579	20.945	22.6	Tx 362 S/N 41 J2700-5	0.125	37.287	46.055	702	625

$\int P dt$ (PSIA SEC)	$\int P dt_a$ (PSIA-SEC)	C* (FT/SEC)	Fmax (LB)	F50%-web (LB)	I (LB SEC)	Isp (SEC)	$\bar{r}$ (IN/SEC)	Cf	Cd
23220	23640	5154	70000	60780	2298000	280.1	0.311	1.749	0.955

NASA DEFINITIONS

tid SEC	ti 10% SEC	ti 70% SEC	ti 90% SEC	tt SEC	tf SEC
0.013	0.082	0.124	0.153	37.400	40.160

$\bar{r}$ INCHES	P MAX PSIA	$\bar{P}$ PSIA	$\int P dt$ PSIA SEC	Fmax LB	$\bar{F}$ LB	It LB-SEC	Isp SEC	C* FT/SEC	W	Cd
0.310	702	623	23640	70000	60610	2298000	280.1	5158	9019	0.956

REMARKS THIOKOL CHEMICAL CORP STANDARD DEFINITIONS ARE APPLIED TO PARAMETERS OUTLINED BY HEAVY BLACK BOUNDRY MOTOR TESTED IN ALTITUDE CHAMBER WITH NOZZLE CLOSURE AND HAD 14.3 PSIA AT IGNITION.

Figure 107. Data Summary of TX354 Motor 5 from Mixes B-2230, B-2232, and B-2303.

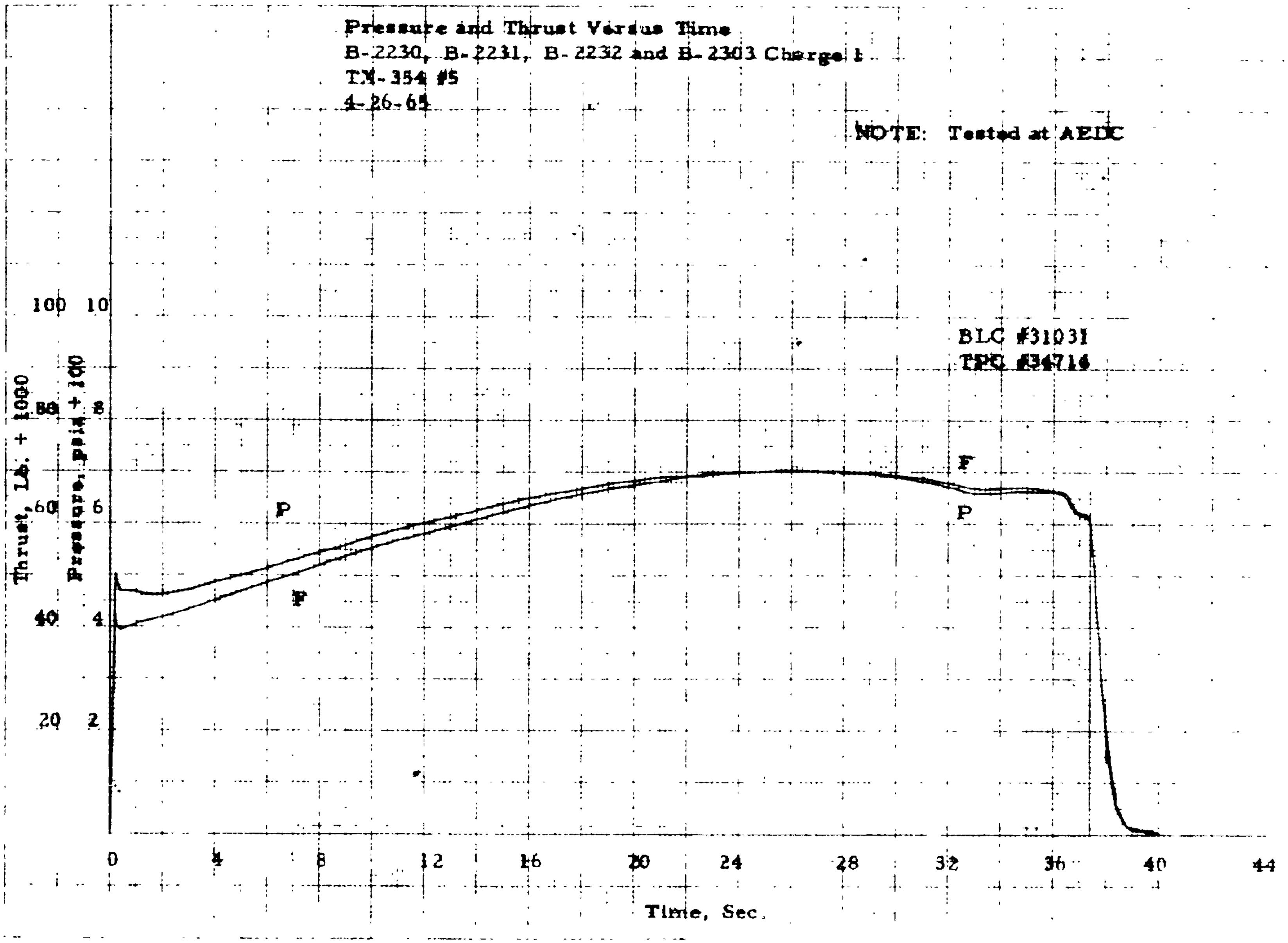


Figure 108. Pressure and Thrust versus Time of TX354 Motor 5.

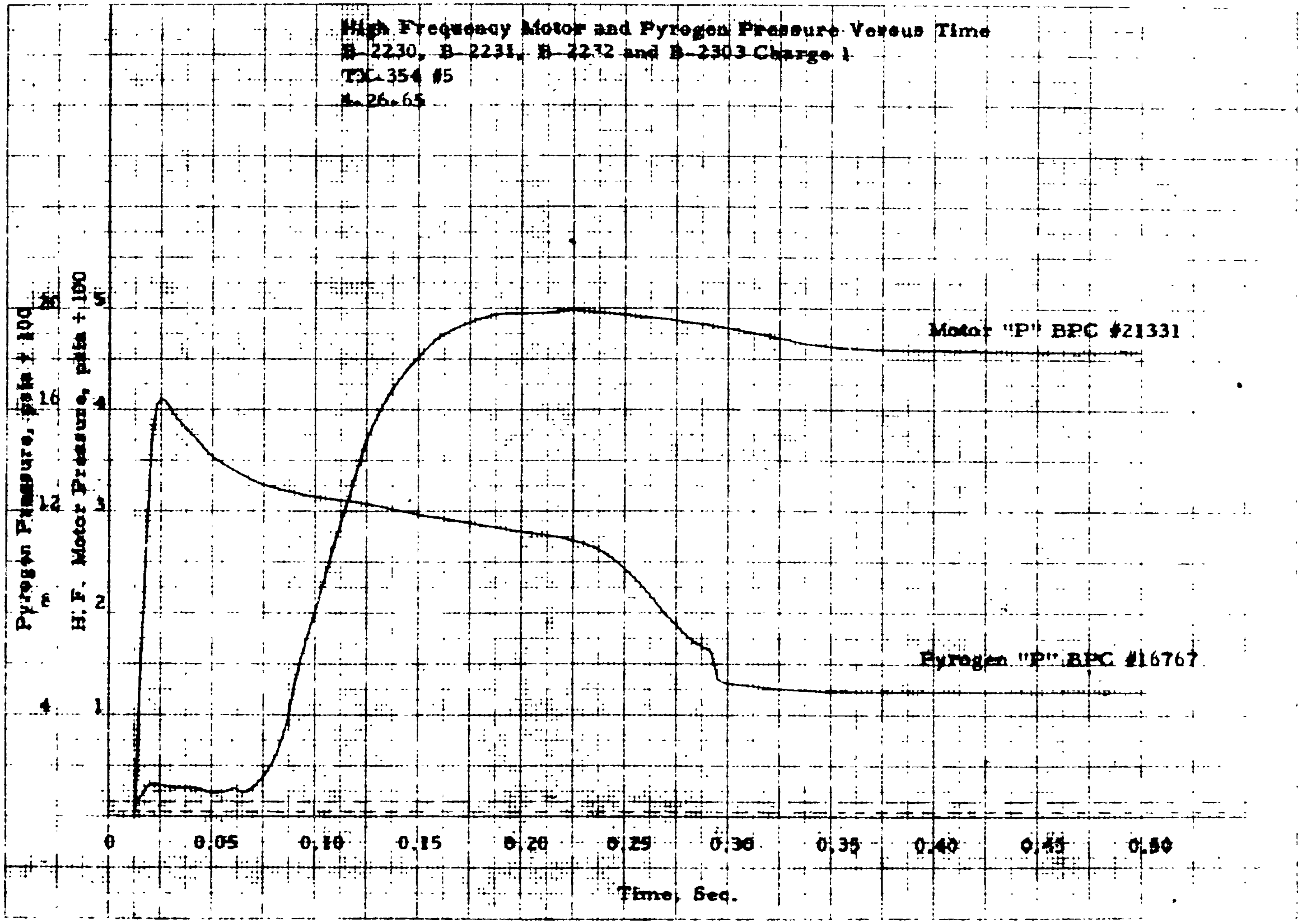


Figure 109. High Frequency Motor and Pyrogen Igniter Pressure versus Time of TX354 Motor 5.

NO. B2287-B2288-B2293-B2295

CHG NO	MOTOR TYPE	PROGRAM	PROPELLANT TYPE	DATE FIRED	DATE CAST	Wp (LB)	Wb (LB)	% PROPELLANT RESIDUE	TEMPERATURE (°F) GRAIN	TEMPERATURE (°F) AMB	BAR PRESS (IN Hg)	% R H
1	[redacted]- 1.35+3 #2	[illegible]	TPH-7025	3-1-65	1-7-65	8212.35			110	57	29.90	62

NOZZLE DIA (IN) BEFORE	NOZZLE DIA (IN) AFTER	$\bar{A}_t$ (IN²)	ΔA_t (IN²)	A_e/A_t			IGNITER	t 50% (SEC)	t 50% web (SEC)	t (SEC)	P max (PSIA)	P 50% web (PSIA)
[illegible] [illegible] [illegible]	5.510 5.523 5.492	55.420	+2.863	7.354	7.194	22.6	TU700-8 S/N TCC-44 TX362	0.110	36.273	38.75	731	651

(PSIA SEC)	∫Pdt (PSIA SEC)	(FT SEC)	F max (LB)	F 50% web (LB)	(LB SEC)		(SEC)		
13620	23370	5204	61290 *419	52300 *338	1923000 *17336	234.2	0.319	1.450	0.965

NASA DEFINITIONS PER TX-33 PROGRAM

t_{id} (SEC)	t_1 10% (SEC)	t_1 70% (SEC)	t_1 90% (SEC)	t_b (SEC)	t_t (SEC)
0.008	0.067	0.108	0.130	36.380	38.100

$\bar{T}$ (SEC)	P_c MAX (PSIA)	$\bar{P}_c$ (PSIA)	∫FdT (LB-SEC)	F_{max} (LB)	$\bar{F}$ (LB)	I_t (LB-SEC)	Isp (SEC)	C* (FT/SEC)	W	Cd
.318	731	649	23170	61210 *419	52160 *337	[illegible] *[illegible]	234.2	**5207	7541	0.955

REMARKS THIOKOL CHEMICAL CORP STANDARD DEFINITIONS ARE APPLIED TO PARAMETERS OUTLINED BY HEAVY BLACK BOUNDRY

* PRELOAD ADDED TO ALL THRUST PARAMETERS - PRELOAD ANGLE COS 21°56'

NOTE: DATA TAKEN FROM "B" BRIDGE OSCILLOGRAPH TRACE.

** ND USED TO CALCULATE C*

Figure 110. Data Summary of TX354 Motor 6 from Mixes B-2287, B-2288, B-2293 and B-2295.

SXH 3-19-66

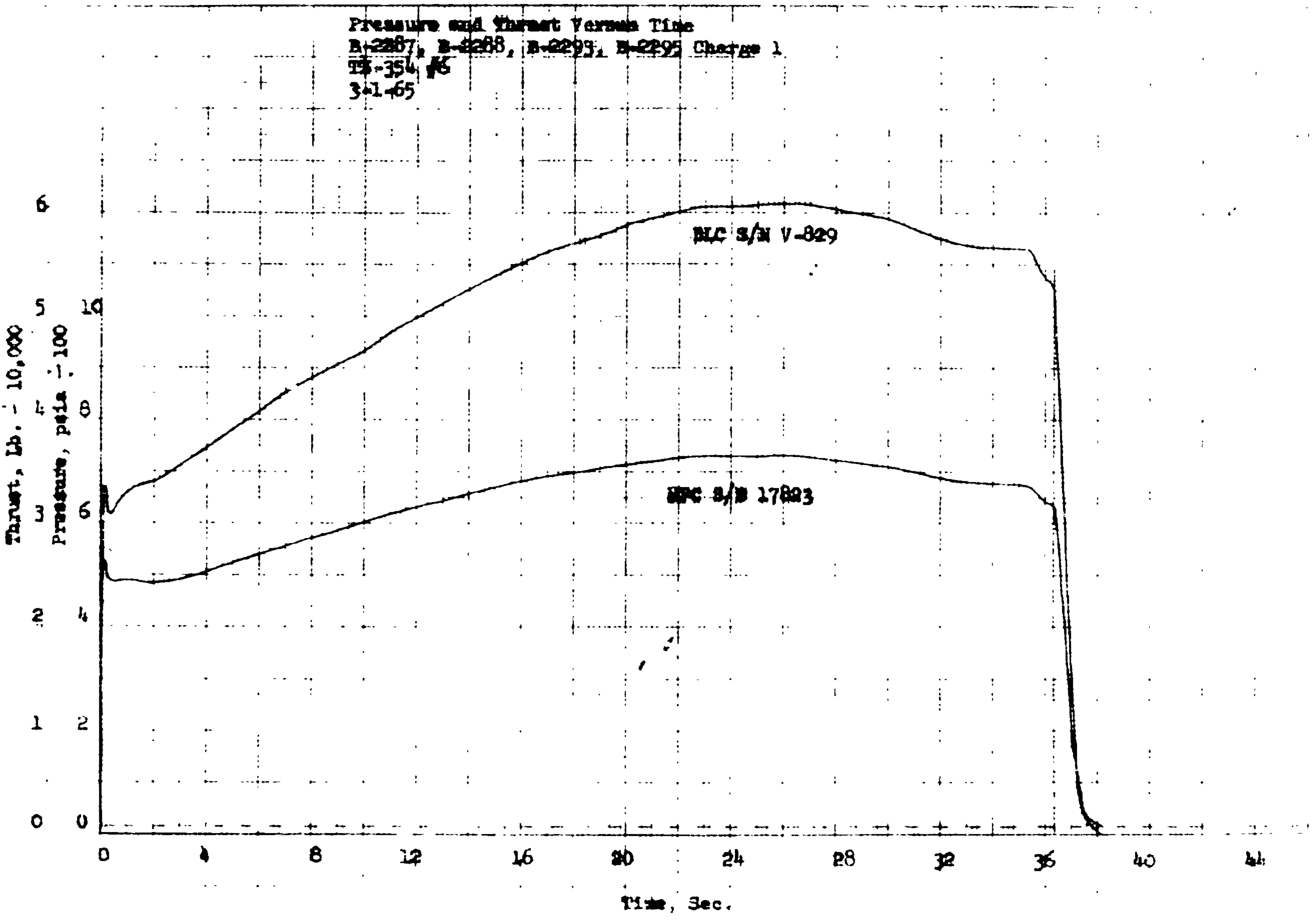


Figure 111. Pressure and Thrust versus Time of TX354 Motor 6.

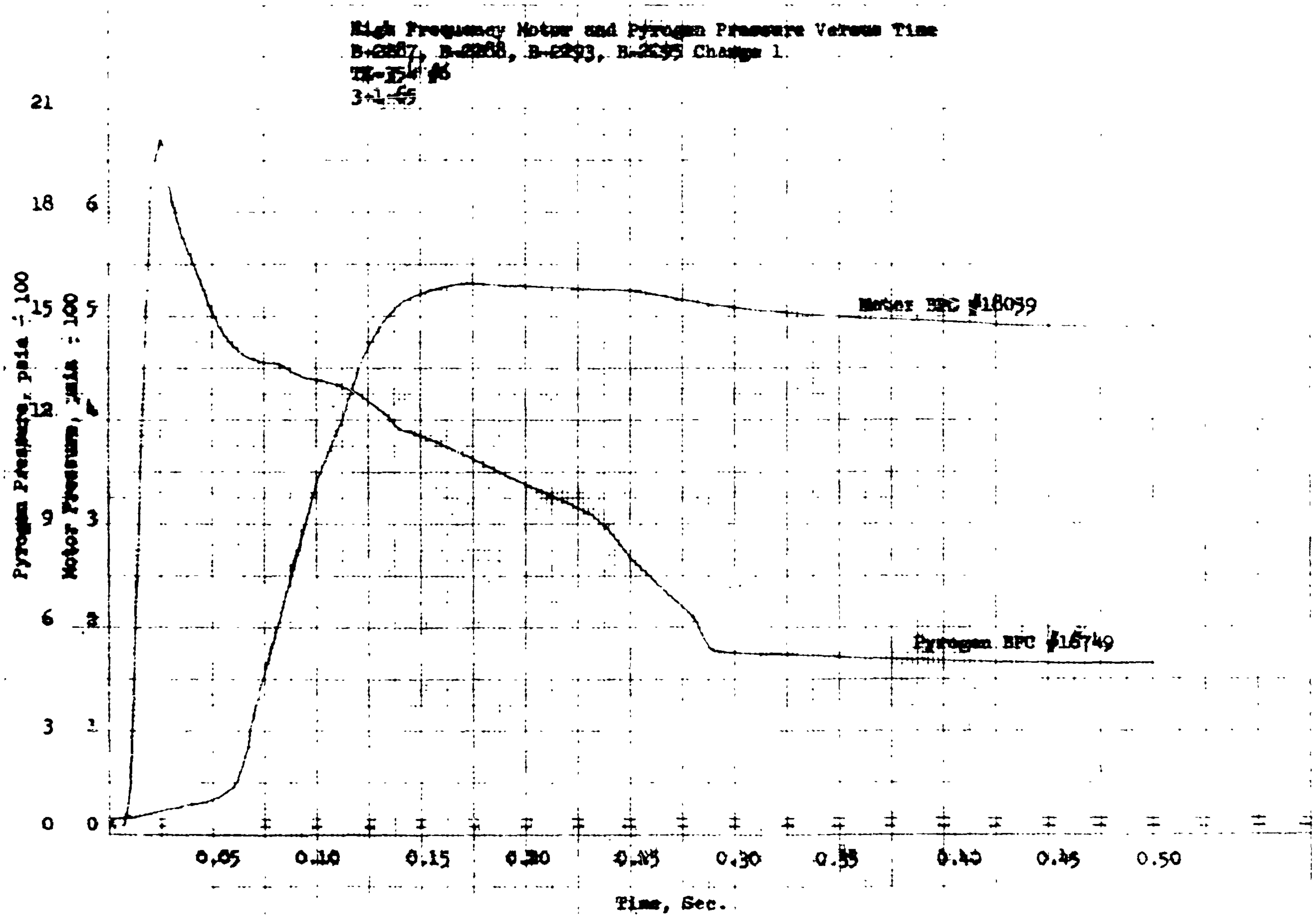


Figure 112. High Frequenc, Motor and Pyrogen Igniter Pressure versus Time of Motor 6.

MIX NO. B2293 THRU B2295 & B22..7

CHG NO.	MOTOR TYPE	PROGRAM	PROPELLANT TYPE	DATE FIRED	DATE CAST	W_p (LB)	W_b (LB)	% PROPELLANT RESIDUE	TEMPERATURE (°F) GRAIN	TEMPERATURE (°F) AMB	BAR PRESS "Hg"	% R H
1	[redacted] TX 354 # 7	CASTOR II	TPH-7025	1-31-65		8200.85			20	27	29.30	56

NOZZLE DIA (IN) BEFORE	NOZZLE DIA (IN) AFTER	$\bar{A}_t$ (IN²)	ΔA_t (IN²)	A_e/A_t	$A_e/\bar{A}_t$	[illegible]	IGNITER	$t_{@50\%}$ (SEC)	$t_{@50\%\ web}$ (SEC)	$t_{@0}$ (SEC)	P max (PSIA)	P 50% web (PSIA)
8239	8528											
8.288	8516	55.501	3.076	7.330	7.127	22.6	J 2700-10 S/N 46	0.210	38.896	40.700	675	610
8291	8521											

$\int P dt$ (PSIA SEC)	$\int P dt_a$ (PSIA-SEC)	C* (FT/SEC)	✱ Fmax (LB)	✱ F 50% web (LB)	✱ I (LB SEC)	✱ Isp (SEC)	r (IN/SEC)	✱ C_f	✱ C_d
23710	24020	5230	55930	48340	1898000	231.4	0.298	1.428	0.987
			✱✱ 412	✱✱ 360	✱✱ 13650				

NASA DEFINITIONS PER TX 33 PROGRAM

t_d (Sec)	$t_{10\%}$ (Sec)	$t_{70\%}$ (Sec)	$t_{90\%}$ (Sec)	t_b (Sec)	t_f (Sec)
0.170	0.185	0.218	0.237	38.941	40.700

$\bar{r}$ (in/sec)	P_c max (PSIA)	$\bar{P}_c$ (PSIA)	$\int_0 P dt$ (PSIA-sec)	Fmax ✱ (lb)	$\bar{F}$ ✱ (lb)	It ✱ (lb-sec)	Isp ✱ (sec)	C✱ (FT/sec)	W ✱	Cd ✱
0.297	675	609	24020	55930	48280	1898000	231.4	5234	7451	0.987
				✱✱ 412	✱✱ 340					

REMARKS THIOKOL CHEMICAL CORP STANDARD DEFINITIONS ARE APPLIED TO PARAMETERS OUTLINED BY HEAVY BLACK BOUNDRY. ✱ Note: First two seconds of Thrust calculated by Ratio to Pressure. Preload added to all Thrust parameters, [illegible] ✱✱ PRESSURE TAKEN FROM HIGH FREQUENCY TAKE. THRUST TAKEN FROM "B" BRIDGE.

Figure 113. Data Summary of TX354 Motor 7 from Mixes B-2293, B-2294, B-2295 and B-2287.

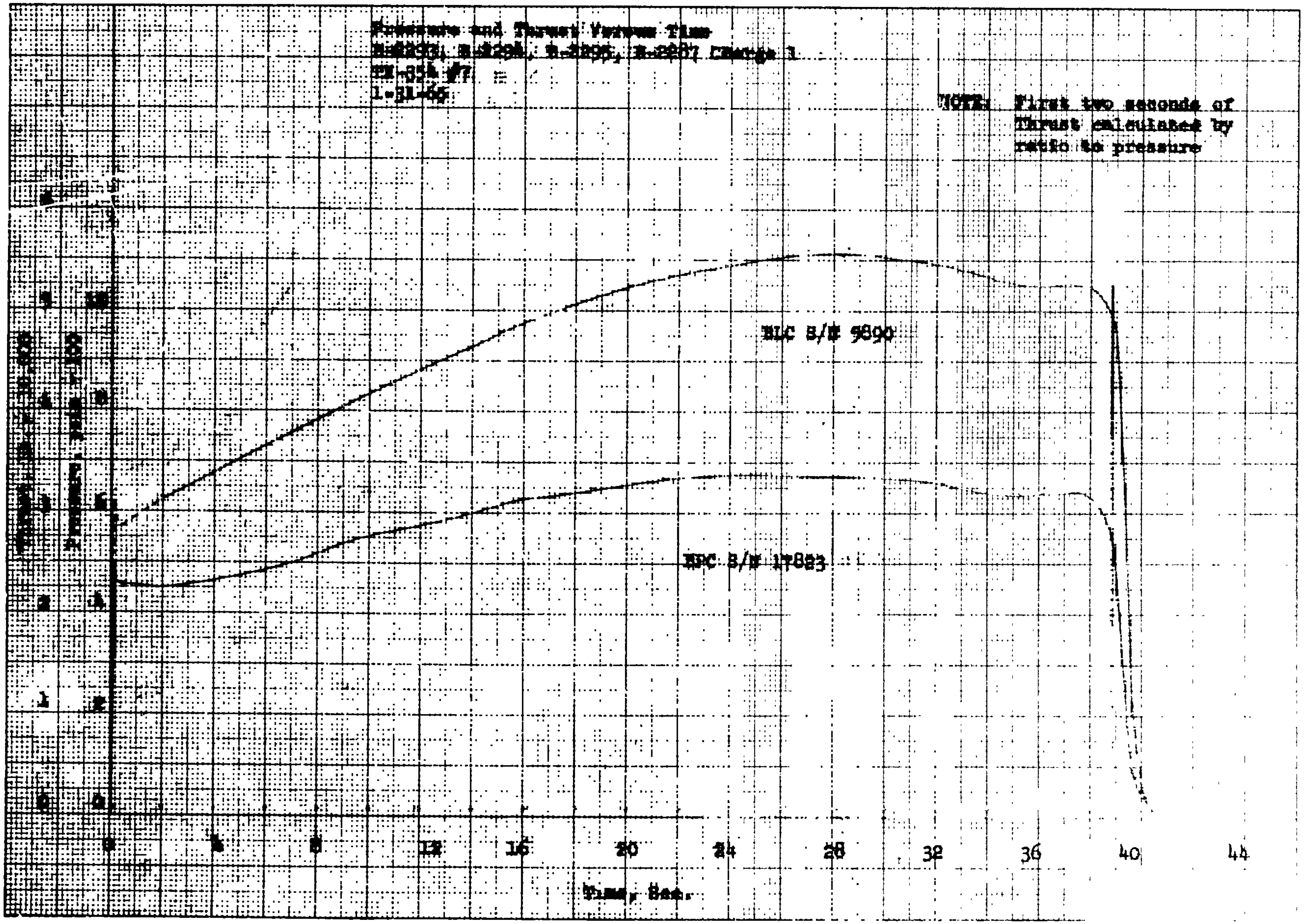


Figure 114. Pressure and Thrust versus Time of TX354 Motor 7.

Corrected Copy 2-24-65

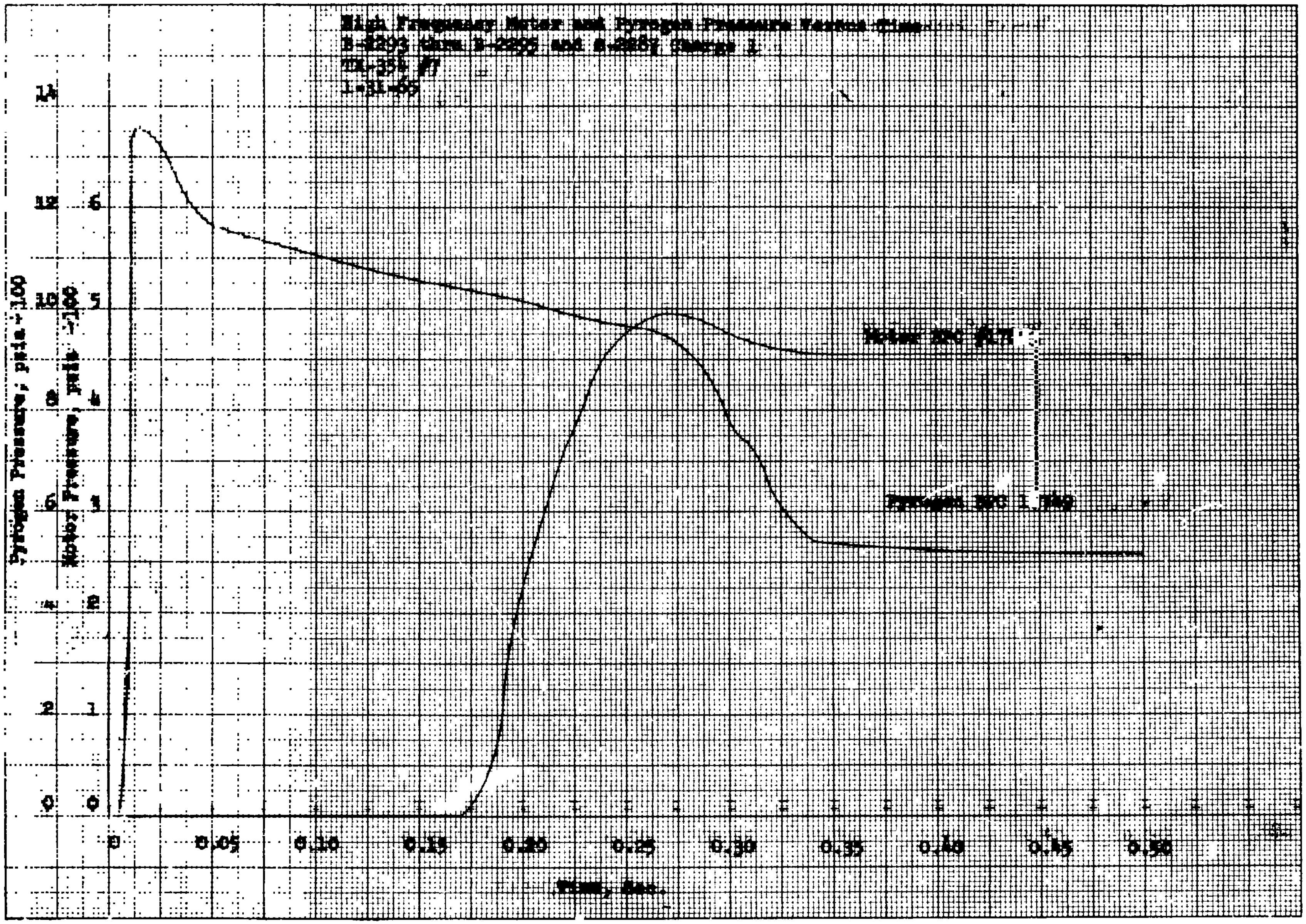


Figure 115. High Frequency Motor and Pyrogen Igniter Pressure versus Time of TX354 Motor 7.

B 2230-2232 & B2302-2303

MOTOR DATA SUMMARY

LINE NO	MOTOR TYPE	PROGRAM	PROPELLANT TYPE	DATE FIRED	DATE CAST	W_p (LB)	W_b (LB)	% PROPELLANT RESIDUE	TEMPERATURE (°F) GRAIN	TEMPERATURE (°F) AMB	BAR PRESS "Hg"	% R.H
1	[redacted]- TX 354 # 22	CASTOR II	TPH-7025	4 30 65		8205.96						

NOZZLE DIA (IN) BEFORE	NOZZLE DIA (IN) AFTER	$\bar{A}_t$ (IN²)	ΔA_t (IN²)	A_e/A_t	[illegible]	[illegible]	[illegible]	[illegible]	% web	[illegible]	[illegible] PSIA	[illegible] PSIA
8.290	8.522 8.5[illegible]2 8.50	55.4[illegible]	2.970	[illegible]	[illegible]	[illegible]	TX 362 [illegible] 2700-2 [illegible] 38	0.135	37.075	39.740	701	630

$\int P dt_1$ (PSIA-SEC)	$\int P dt_2$ (PSIA-SEC)	C* (FT/SEC)	Fmax (LB)	F50% web (LB)	I_t (LB-SEC)	t_b (SEC)	r (IN/SEC)	[illegible]	[illegible]	AREA DEFINITIONS					
23540	23760	5166	71000	61[illegible]0	23[illegible]	[illegible]5	[illegible]	[illegible]764	0.944	[illegible]	[illegible]87	0.131	[illegible].57	37[illegible]	[illegible]

$\bar{t}$ (IN SEC)	Pc MAX (PSIA)	$\bar{P}_c$ (PSIA)	$\int P dt$ (PSIA-SEC)	F MAX (LB)	$\bar{F}$ (LB)	I_t (LB-SEC)	I_{sp} (SEC)	C* (FT/SEC)	N	Cd
[illegible]2.2	701	628	23760	71000	[illegible]480	[illegible]	[illegible]	[illegible]	[illegible]9	0.9[illegible]

REMARKS THIOKOL CHEMICAL CORP STANDARD DEFINITIONS ARE A[illegible] [illegible] PARAMETERS OUTLINED BY HEAVY BLACK BOUNDRY NOTE: MOTOR TESTED IN ALTITUDE CHAMBER WITH NOZZLE CLOSURE AND HAD 11 PSIA AT IGNITION.

Figure 116. Data Summary of TX354 Motor 22 from Mixes B-2230, B-2232, B-2302 and B-2303.

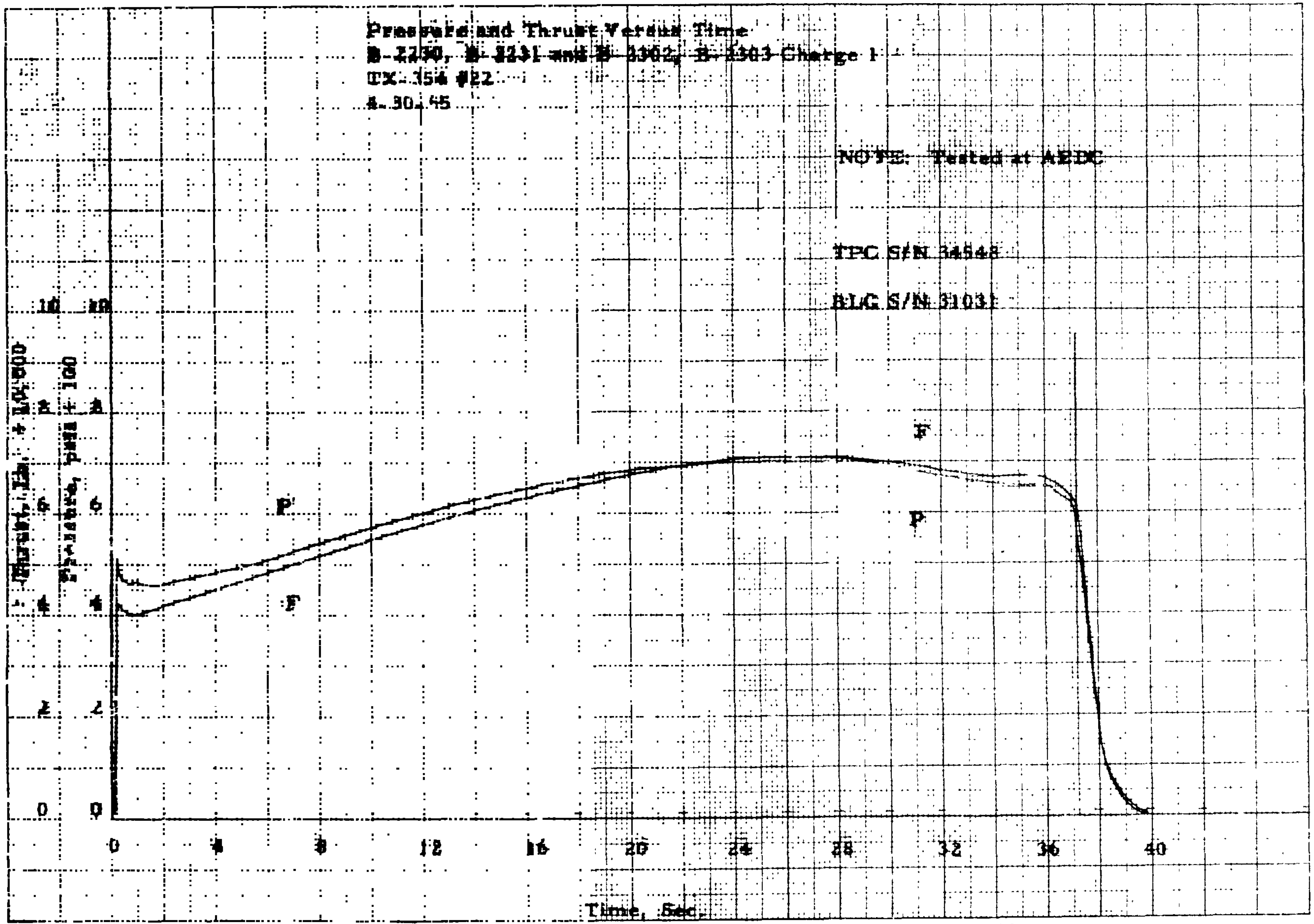


Figure 117. Pressure and Thrust versus Time of TX354 Motor 22.

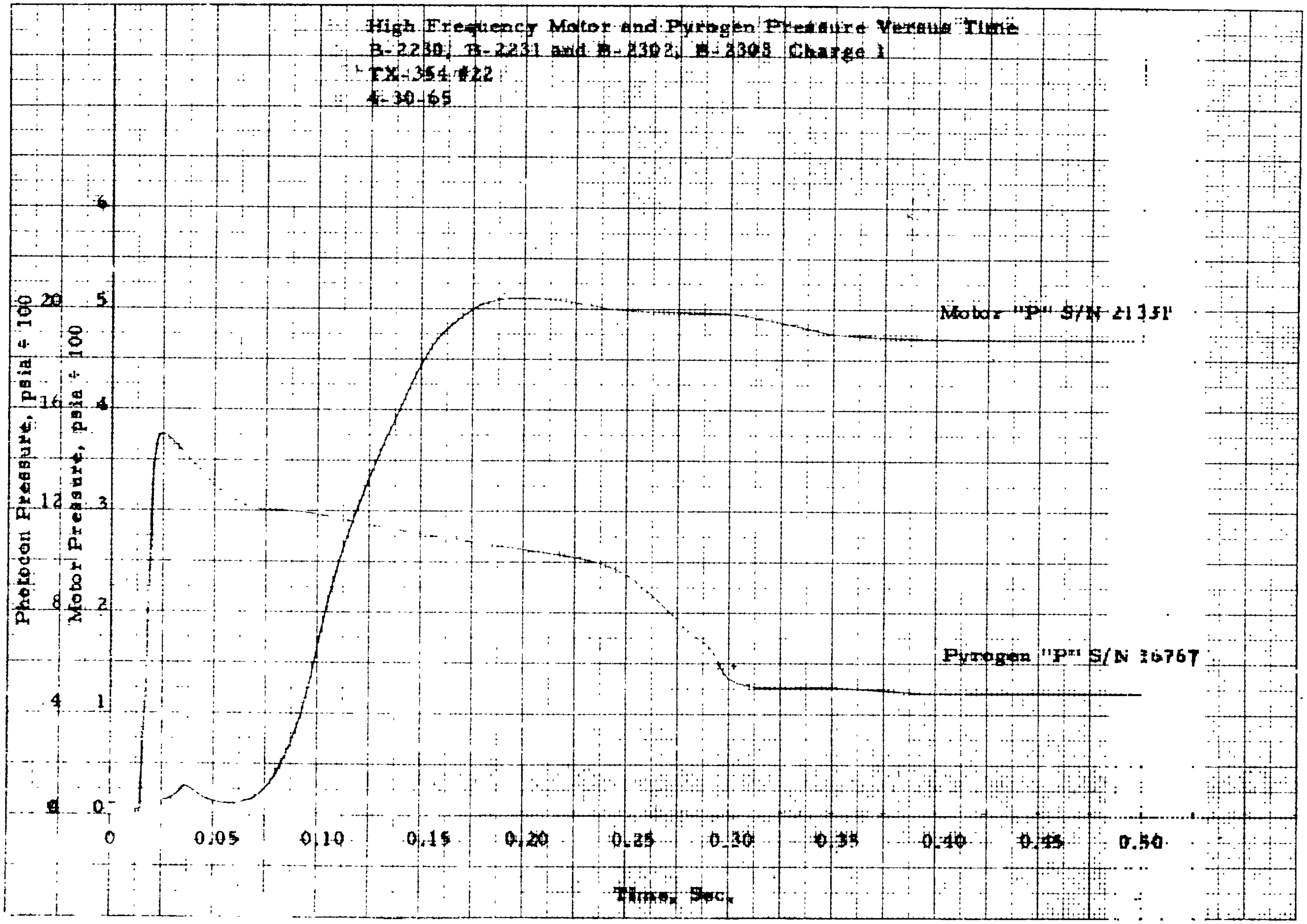


Figure 118. High Frequency Motor and Pyrogen Igniter Pressure versus Time of TX354 Motor 22.

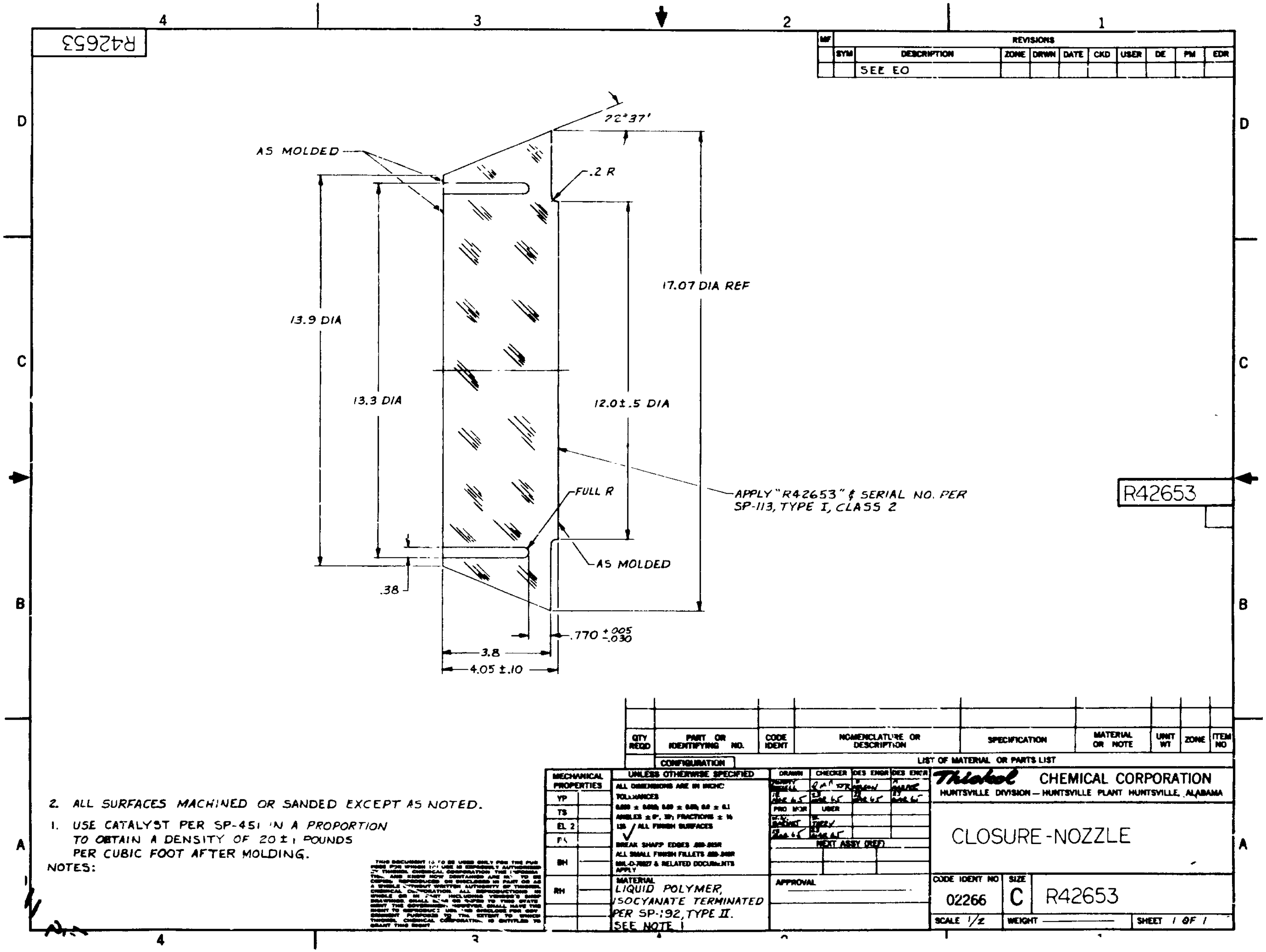
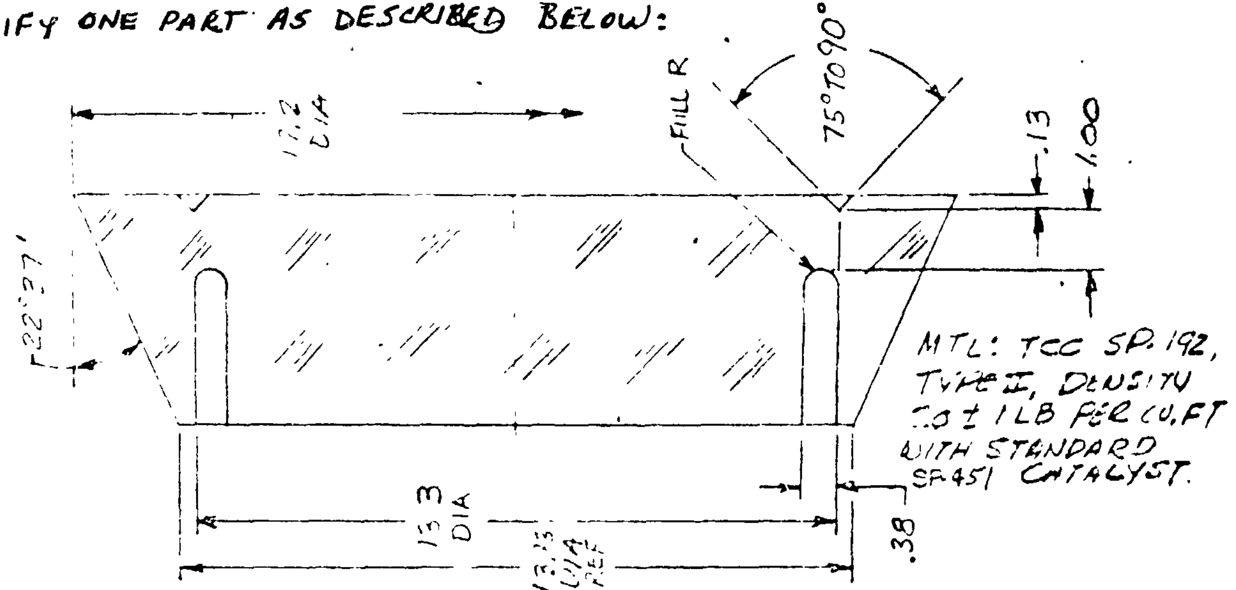


Figure 119. Nozzle Closure Design of the TX354 Motor.

DETAILED DESCRIPTION (CHANGES AND REASON, ATTACH SKETCHES AS REQUIRED)

* MODIFY ONE PART AS DESCRIBED BELOW:

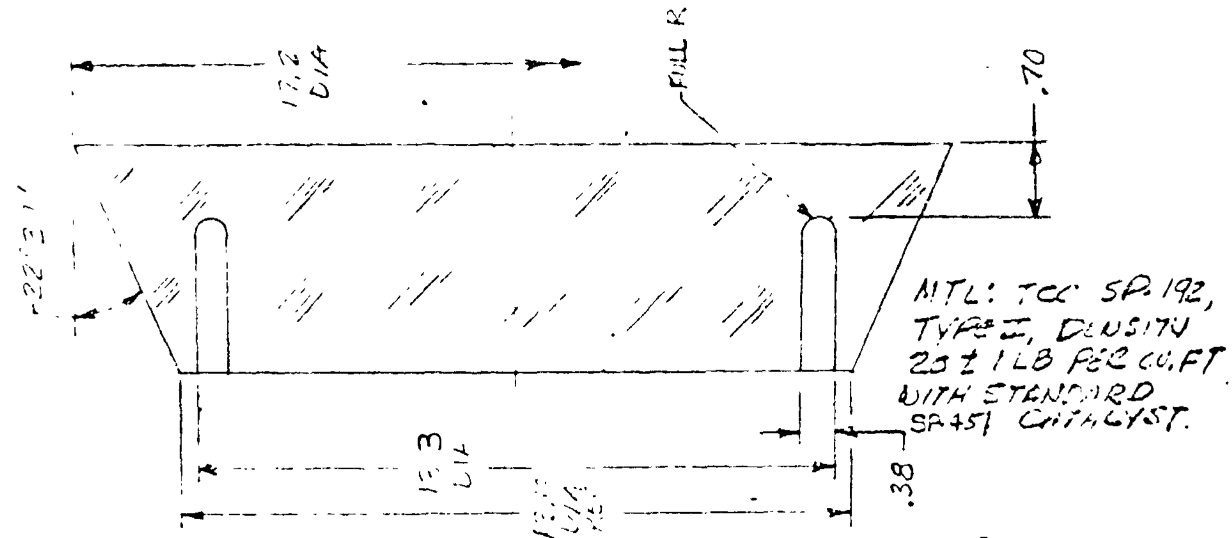


REASON TO PROVIDE TEST CLOSURE FOR CASTOR II PROGRAM
SYSTEM 3 DOCUMENTATION

Figure 120. Closure Design Test 1.

DETAILED DESCRIPTION (CHANGES AND REASON, ATTACH SKETCHES AS REQUIRED)

* MODIFY ONE PART AS DESCRIBED BELOW:

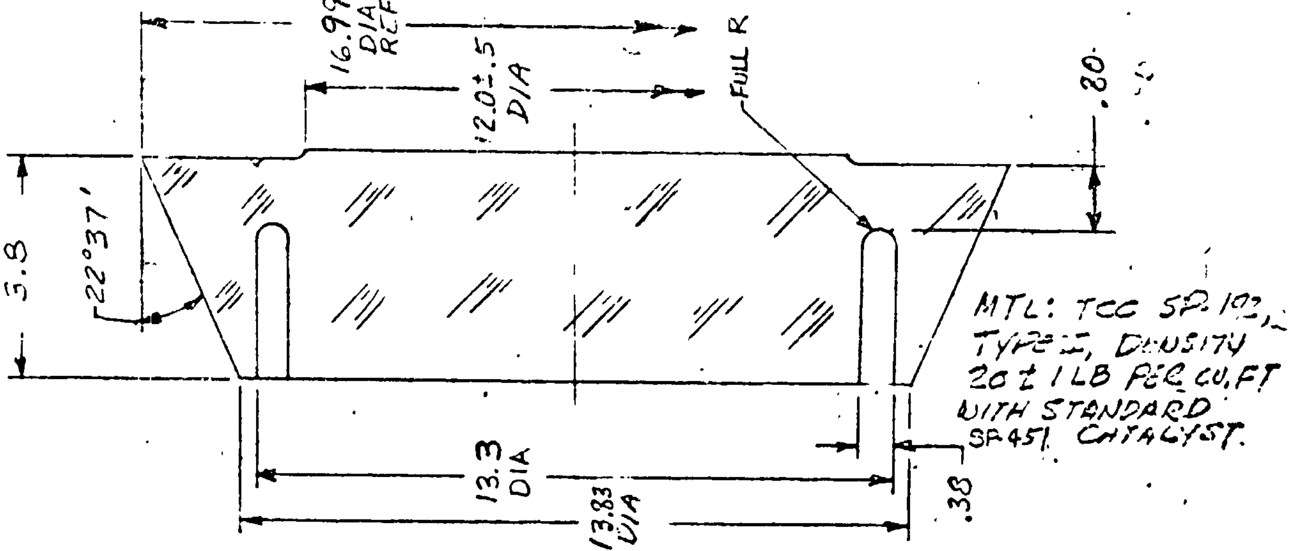


REASON TO PROVIDE TEST CLOSURE FOR CASTOR II PROGRAM
SYSTEM 3 DOCUMENTATION

Figure 121. Closure Design Test 2.

DETAILED DESCRIPTION (CHANGES AND REASON, ATTACH SKETCHES AS REQUIRED)

* MODIFY 3 PARTS AS DESCRIBED BELOW:

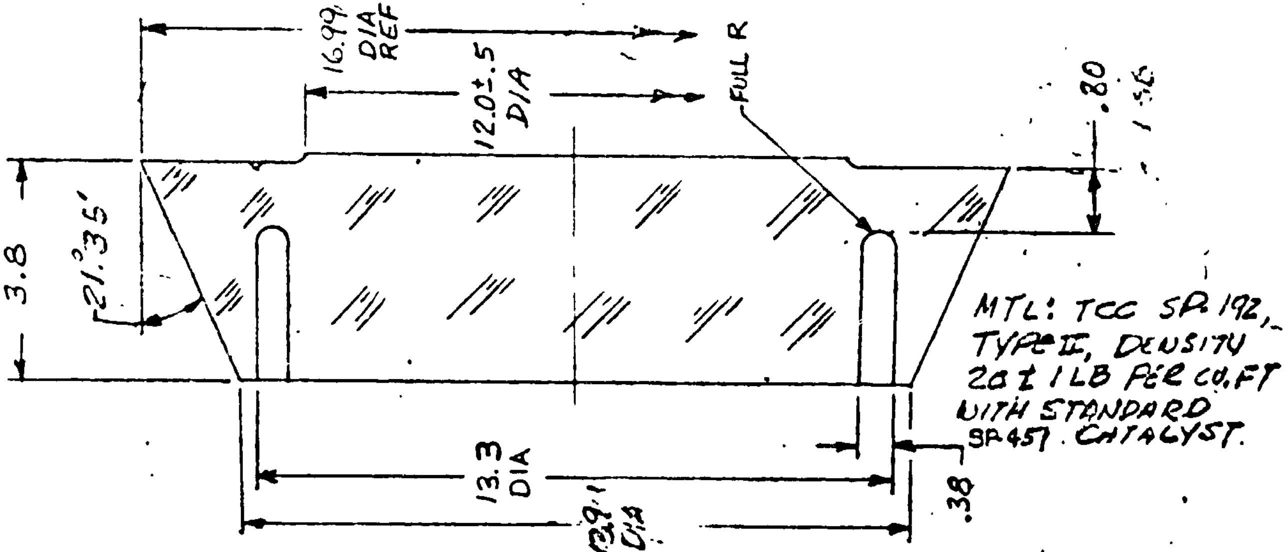


REASON: TO PROVIDE TEST CLOSURE FOR CASTOR II PROGRAM
SYSTEM 3 DOCUMENTATION

Figure 122. Closure Design Tests 3 through 6.

DETAILED DESCRIPTION (CHANGES AND REASON, ATTACH SKETCHES AS REQUIRED)

* MODIFY ONE PART AS DESCRIBED BELOW:

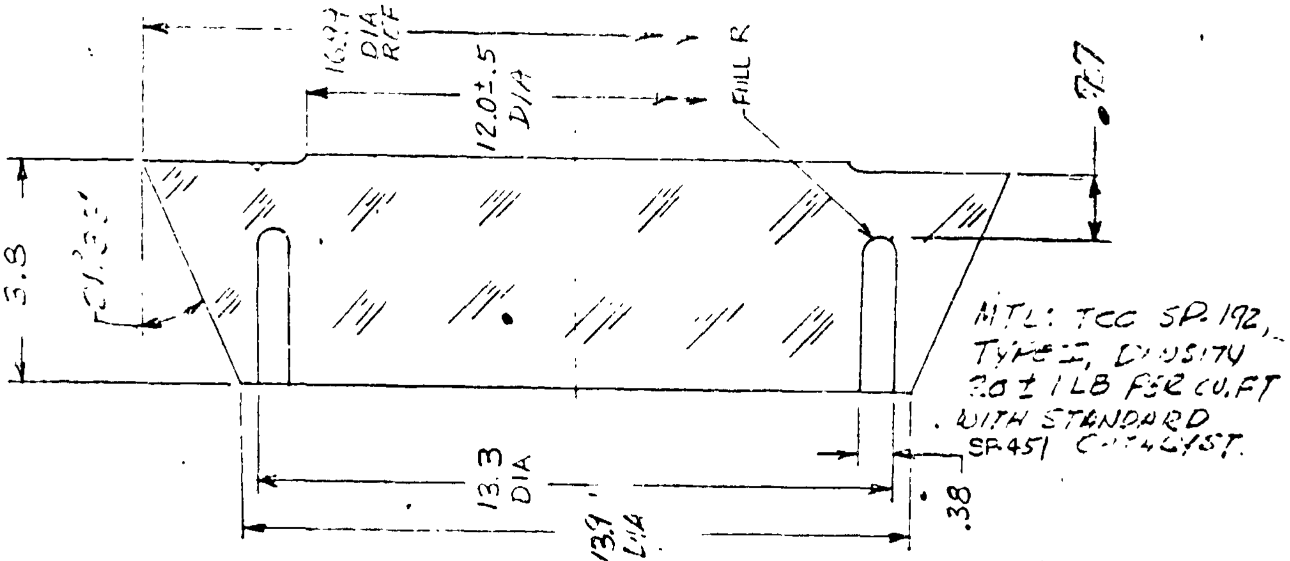


REASON: TO PROVIDE TEST CLOSURE FOR CASTOR II. PROGRAM
SYSTEM 3 DOCUMENTATION

Figure 123. Closure Design Test 7

DETAILED DESCRIPTION (CHANGES AND REASON, ATTACH SKETCHES AS REQUIRED)

* MODIFY THE PART AS DESCRIBED BELOW:



REASON TO PROVIDE TEST CLOSURE FOR CASTOR II PROGRAM
SYS. [illegible] DOCUMENTATION ECN

Figure 124. Closure Design Tests 8 through 12.

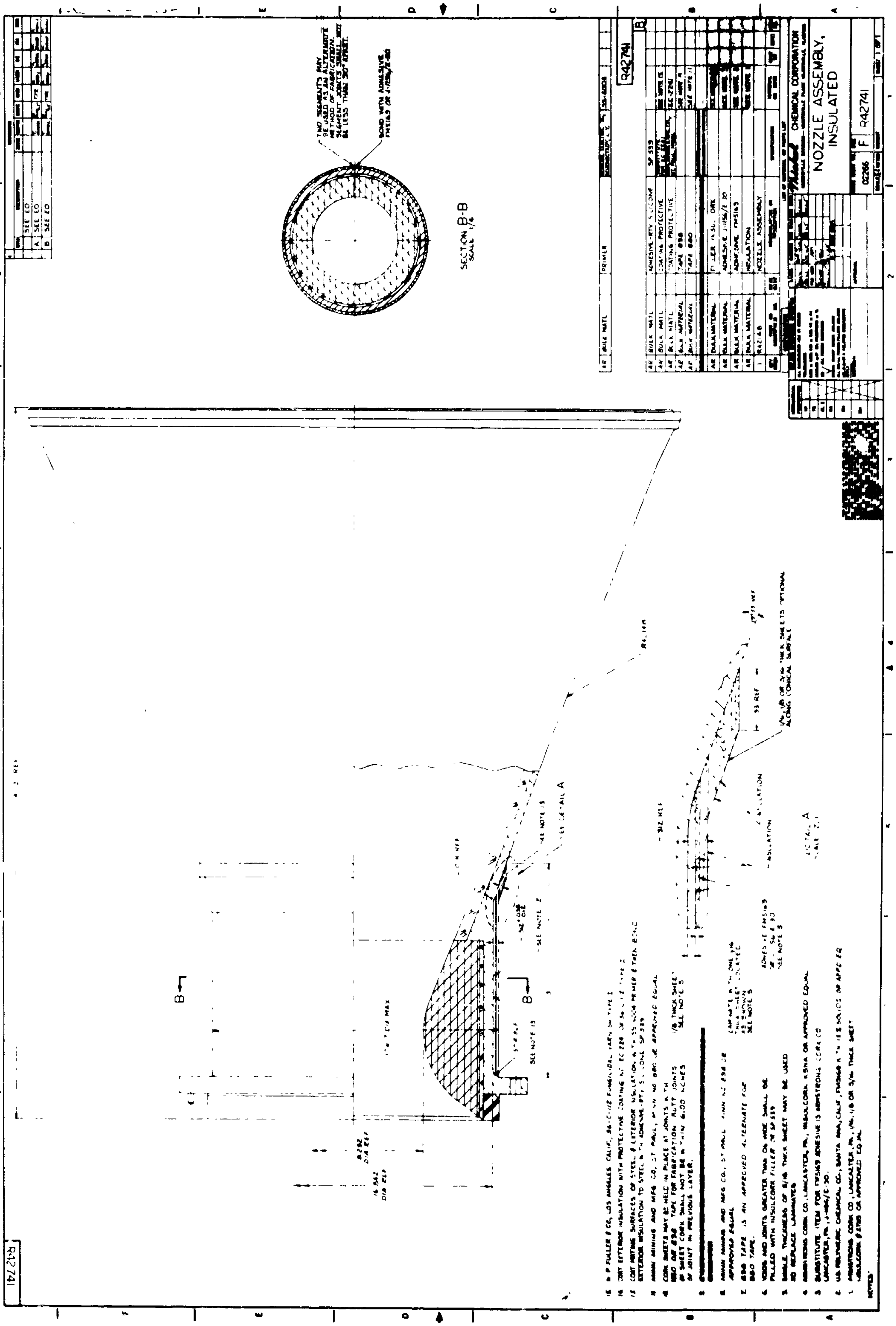


Figure 125. External Insulation Developed for the Castor IIA Motor.

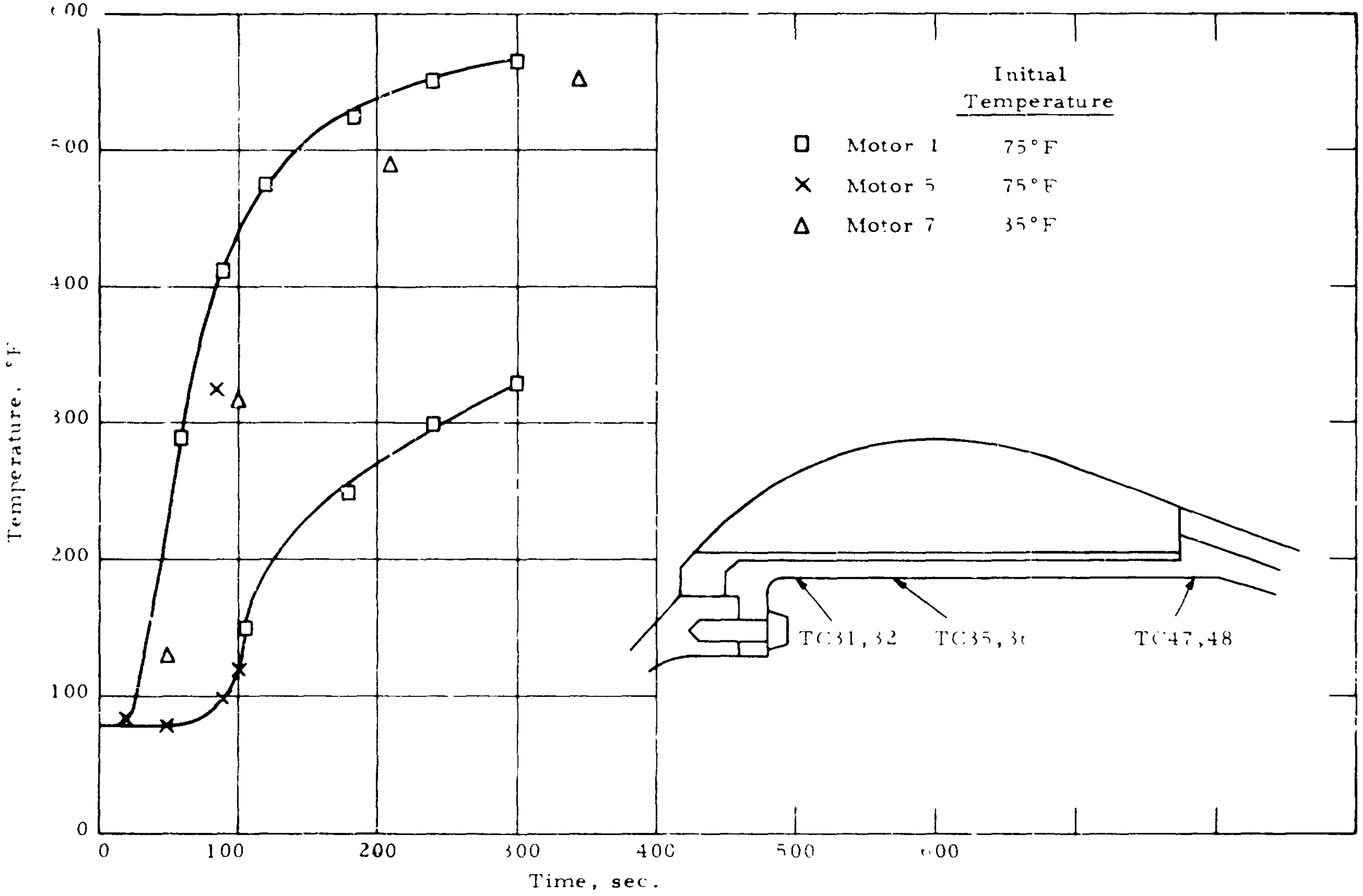


Figure 126. Steel Nozzle Exterior Temperature Data for Various TX-354 Motor Tests.

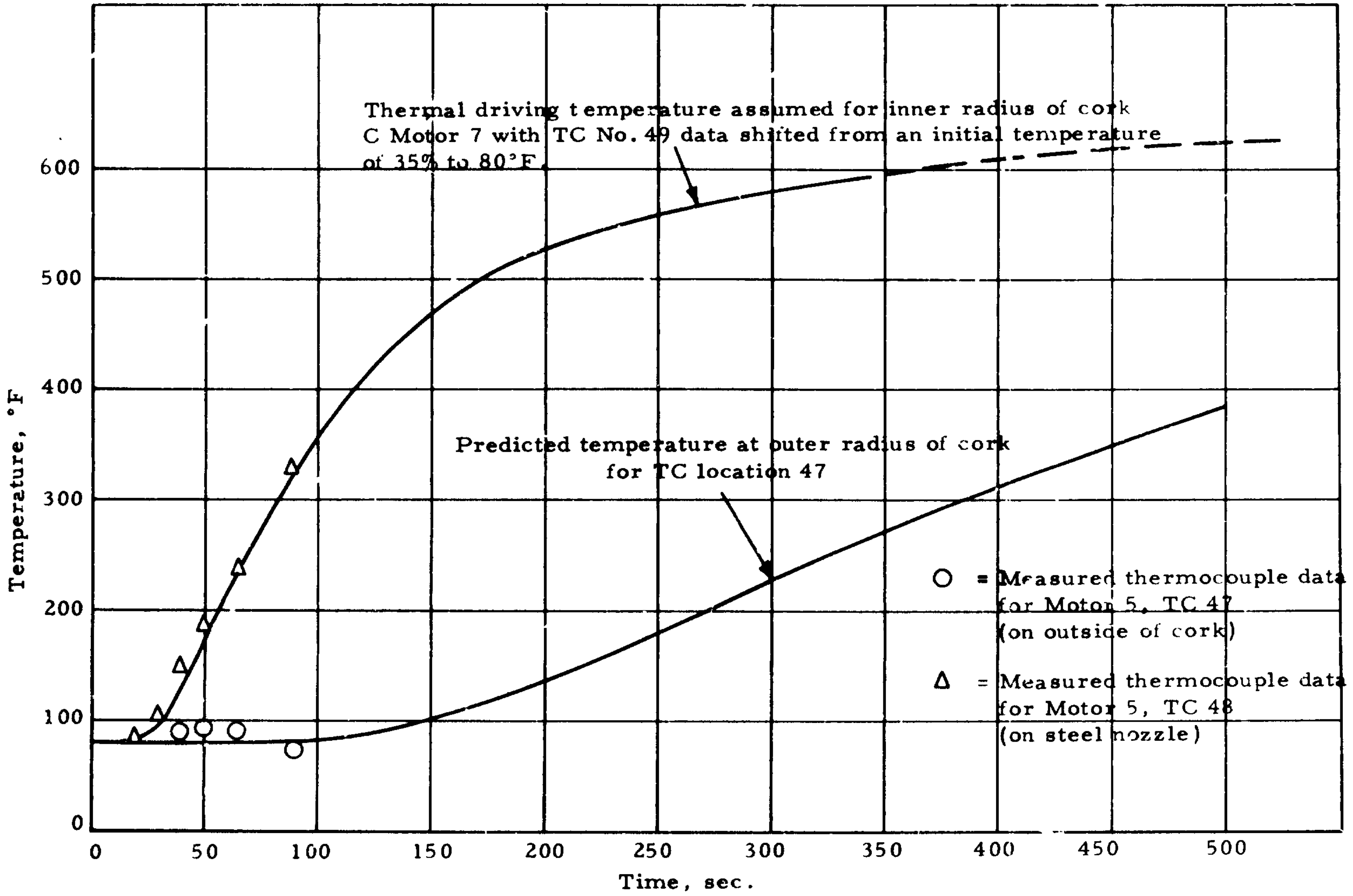


Figure 127. Predicted Temperature for Exterior of Cork Blanket at Hottest Location.

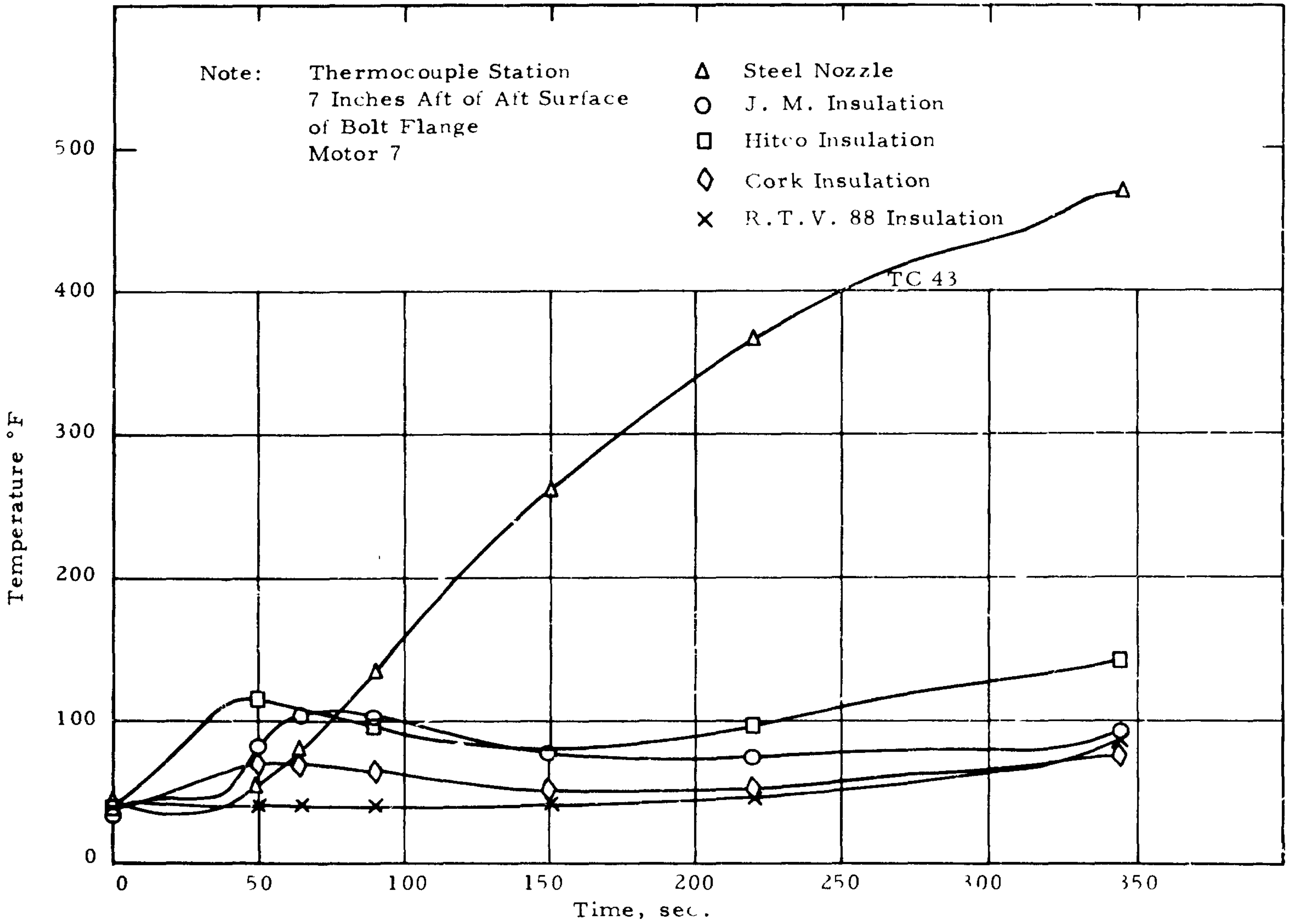


Figure 128. Temperature Data From Motor 7.

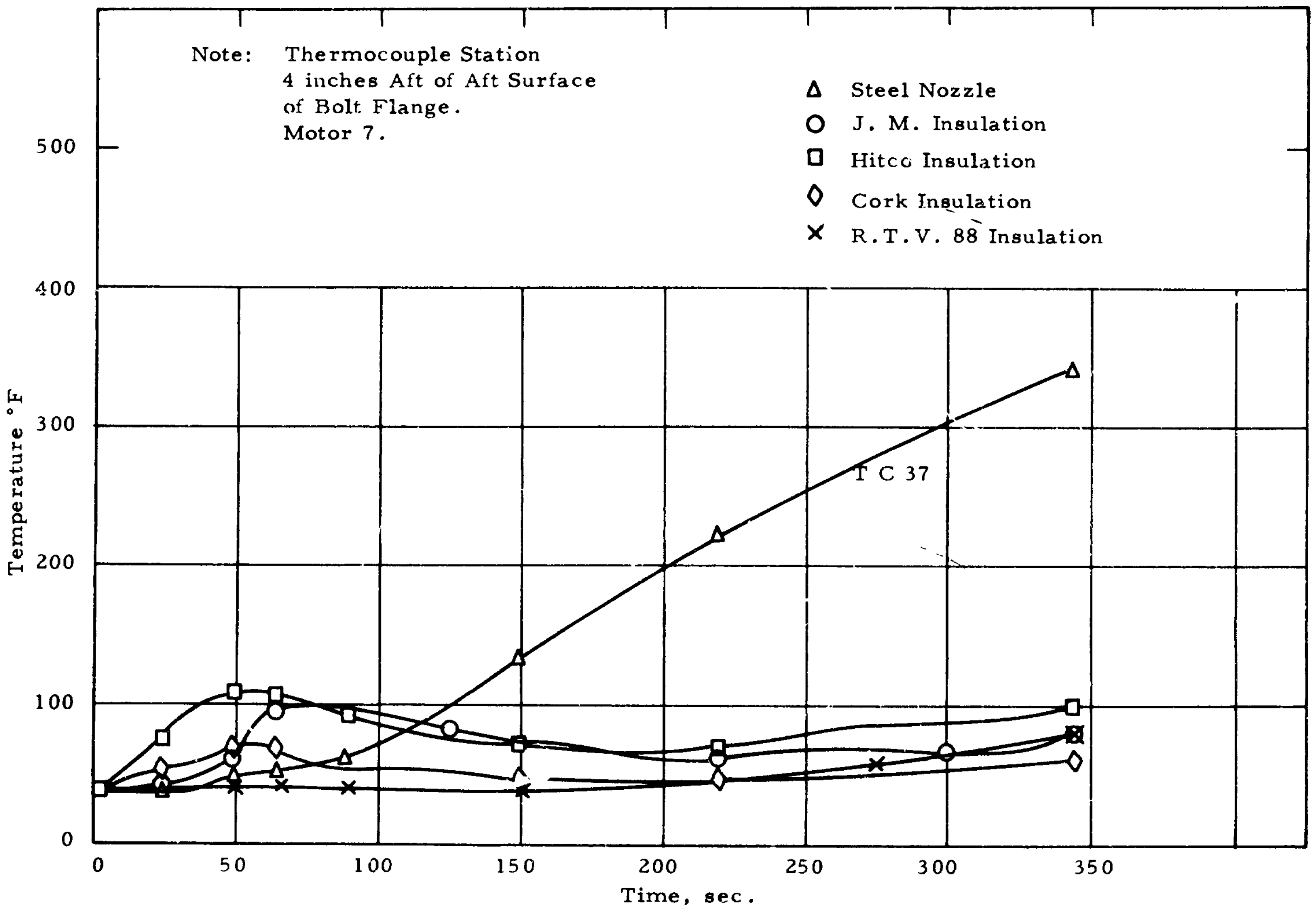


Figure 129. Temperature Data From Motor 7.

APPENDIX A

LIST OF REPORTS SUBMITTED UNDER THE CONTRACT

BLANK PAGE

APPENDIX A

LISTING OF REPORTS SUBMITTED

Control Number	Title	Date	Classification
C-63-4540	General Arrangement Drawing and Performance Manual for the TX354 Castor II Rocket Motor	18 Nov. 63	Confidential
C-65-4456A	General Arrangement Drawing and Performance Manual for the Castor II Rocket Motor (Revision 1)	3 Feb 65	Confidential
C-65-4491A	General Arrangement Drawing and Performance Manual TX354-3 Castor IIA Rocket Motor (Rev 2)		Confidential
C-65-4492A	General Arrangement Drawing and Performance Manual for the TX354-4 Castor IIA Rocket Motor		Confidential
U-65-4554	Stress Report for the TX354 Castor II Rocket Motor	10 Jan 64	None
U-64-4458	Manufacturing Equipment Description List for Castor II Rocket Motors	20 Jan 64	None
U-64-4207	RER 840 "Weight, Center of Gravity and Moment of Inertia Analysis for TX354 (Castor II"	25 March 64	None
U-65-11A	Special Report "An Analysis of the Circumferential Slot Effects on the Internal Ballistics of the TX354 Motor"	Dec 1964	None
U-65-4459	Technical Handling Manual Castor II Rocket Motor (TX354)	12 April 65	None
U-65-4483	Special Report "Shipping Container Analysis Castor II TX354"	April 1965	None
C-64-1026A	Test Report "TX354 Rocket Motor No. 1 March 12, 1964 Development Test 1, Castor II Program"	15 April 64	Confidential
C-64-1064A	Test Report "TX354 Rocket Motor No. 3 Development Test 2 Castor II Program"	March 12, 64	Confidential
C-65-1001A	Test Report "TX354-3 Rocket Motor No. 4 Development Test 3 , 24 Sept 64"	9 July 65	Confidential
C-65-1023A	Test Report" TX354-3 Rocket Motors 6, 7, 5 and 22 Pre Flight Rating Test Castor II Program"		Confidential
U-65-3A	Test Report "TX354 Rocket Motor Hydrostatic Test Conducted 30 June 64	15 Jan 65	None

Control Number	Title	Date	Classification
C-63-4544A	Status Letter - Castor II Rocket Motor (U)	Thru 8 Nov 63	Conf.
C-63-4550A	Status Letter - Castor II Rocket Motor (U)	8 Nov -8 Dec 63	Conf.
C-64-4453A	Status Letter - Castor II Rocket Motor (U)	9 Dec - 8 Jan 64	Conf.
C-64-4467	Status Letter - Castor II Rocket Motor (U)	9 Jan - 8 Feb	Conf.
C-64-4481	Status Letter - Castor II Rocket Motor (U)	9 Feb - 8 Mar	Conf.
C-64-4490	Status Letter - Castor II Rocket Motor (U)	9 Mar - 8 Apr.	Conf.
C-64-4499	Status Letter - Castor II Rocket Motor (U)	9 Apr - 8 May	Conf.
C-64-4507	Status Letter - Castor II Rocket Motor (U)	9 May - 8 June	Conf.
C-64-4512	Status Letter - Castor II Rocket Motor (U)	9 June - 8 July	Conf.
C-64-4519	Status Letter - Castor II Rocket Motor (U)	8 July - 8 Aug.	Conf.
C-64-4535	Status Letter - Castor II Rocket Motor (U)	8 Aug - 8 Sept	Conf.
C-64-4553	Status Letter - Castor II Rocket Motor (U)	9 Sept - 8 Oct	Conf.
C-64-4566A	Status Letter - Castor II Rocket Motor (U)	9 Oct - 8 Nov	Conf.
C-65-4452	Status Letter - Castor II Rocket Motor (U)	9 Nov - 8 Dec	---
U-65-4455A	Status Letter - Castor II Rocket Motor (U)	9 Dec - 8 Jan 65	---
None	Status Letter - Castor II Rocket Motor (U)	9 Jan - 8 Feb	---
None	Status Letter - Castor II Rocket Motor (U)	9 Feb - 8 March	---
None	Status Letter - Castor II Rocket Motor (U)	9 March - 8 April	----
None	Status Letter - Castor II Rocket Motor (U)	9 April - 8 May	---
None	Status Letter - Castor II Rocket Motor (U)	9 May - 8 June	---
None	Status Letter - Castor II Rocket Motor (U)	9 June - 8 July	---

ATHENA TEST REPORTS

Control Number	Title	Date	Classification
C-64-1077A	Test Report "TX354-2 Rocket Motor No. 8 16 July 64 Development Test Motor for Athena Program	22 Dec 64	Confidential
C-65-1015A	Test Report "TX354- Rocket Motor No. 9 14 August 64 Development Test Motor for Athena Program		Confidential
C-65-1013A	Test Report "TX354- Rocket Motor No. 11 24 September 65 Development Test Motor for Athena Program		Confidential
C-65-1022A	Test Report "TX354- Rocket Motor No. 12 Development Test Motor for Athena Program		Confidential

APPENDIX B

MASTER PARTS LIST AR-42300

Thiokol CHEMICAL CORPORATION
ALPHA DIVISION - HUNTSVILLE PLANT
HUNTSVILLE, ALABAMA

AR-[illegible] 3 [illegible] REV. 0 MASTER PARTS LIST CHARGE 510-56-67

TX 354-3 SH 1 OF 4 SERVICE MTR. SER. NO. DATE 210665

PART NUMBER	REV.	NAME	REQ.	DATE	REMARKS
R41927		SHIPPING ASSY-MOTOR			
BULK MATL		TAPE PPP-T-60	AR		
CR38688		SHIPPING ASSY-INITIATOR	1		
R42653		CLOSURE-NOZZLE	1		
R41926		MOTOR ASSY-SHIPPING	1		
R42224		MOTOR SUB ASSEMBLY	1		
MS51097-116		SCREW-CAP-HEX HD	4		
R42919		DISK	1		
BULK MATL		LACQUER-LUSTERLESS	AR		MIL-L-11195
MS122[illegible]36		WASHER-LOCK	4		
MS213[illegible]4-5		NUT-HEX HD	4		
BR26989		SPACER	2		
CR263[illegible]4		BAND-LIFTING	2		
BULK MATL		LACQUER MIL-L-11195	AR		
BULK MATL		PRIMER MIL-P-52192	AR		
BULK MATL		PRIMER MIL-P-11414	AR		SEE NOTE 1
BULK MATL		PRIMER SP-404	AR		SEE NOTE 1
R41810		CONTAINER ASSY	1		
7-16-728		CONTAINER ASSY	1		
		CONTAINER-DOCUMENT	1		
BULK MATL		ADHESIVE	AR		MIL-A-1154
		CAP	2		
		CHANNEL	2		
		PLATE	2		
		PLATE	1		
J 5391-020		SANDWICH MOUNTING	12		
		BOLT-HEX HD	96		
		WASHER-LOCK	96		
R42284		BOLT-T	53		
S-1019		BOLT-T	53		SEE NOTE 7
		NUT-HEX	53		
		PLATE	4		
		GASKET	1		
CR38688		SHIPPING ASSY-INITIATOR	1		
BULK MATL		WIRE-LOCK MS20995C32	●		● 4 FOOT
BULK MATL		ENAMEL TT-E-489	AR		
MS24347-1		CONTAINER	1		
CR28434		LABEL-INITIATOR SHIPPING	1		
R42737		PACKING-COATED	2		
CR28207		PACKING-INITIATOR	1		
BULK MATL		COATING-CONDUCTIVE	AR		
BR38707		INITIATOR ASSY-SHIPPING	2		
MS35769-15		GASKET	1		
CR38682		INITIATOR ASSY	1		
BR39724		CLOSURE-PROTECTIVE	1		
BR40179		CLOSURE-PROTECTIVE	1		SEE NOTE 2
CR40776		CAP ASSY-SHORTING	1		SEE NOTE 3
BR37545		CAP-SHORTING	1		
CR39726		CONNECTOR-ELECTRICAL	1		
BR39727		COMPOUND-POTTING	AR		
BULK MATL		COMPOUND IA-L718	AR		SP-408
BULK MATL		WIRE QQ-W-343, TYPE S	AR		
R42921		SHIPPING ASSY-PYROGEN	1		
R41728		PYROGEN UNIT	1		

Thiokol CHEMICAL CORPORATION
ALPHA DIVISION - HUNTSVILLE PLANT
HUNTSVILLE, ALABAMA

AR-42300 REV. D MASTER PARTS LIST CHARGE 510-56-67

TX354-3 SH 2 OF 4 SERVICE MTR.SER.NO. DATE 210665

	PART NUMBER	REV.	NAME	REQ.	DATE	REMARKS
1	R42710		CONTAINER	1		
2	BR28458-051		GASKET	1		
3	MS9068-248		O RING	1		
4	2-248-S417-7		O RING	1		NOTE 4
5	BULK MATL		BAG-CONDUCTIVE	AR		
6	BULK MATL		PACKING	AR		
7	BULK MATL		DESICCANT MIL-D-3464	•		• 16 UNITS
8	BULK MATL		PAINT	AR		
9	R42224		MOTOR SUBASSEMBLY			
10	MS9068-248		O RING	1		
11	2-248-S417-7		O RING	1		SEE NOTE 4
12	NAS150DH30		BOLT	32		
13	BULK MATL		SEALER-TAMPER INDICATING	AR		SP-467
14	BULK MATL		LUBRICANT-CELVACENE	AR		
15	BULK MATL		DESICCANT MIL-D-3464	•		• 30 UNITS
16	BULK MATL		LUBRICANT MIL-M-7866	AR		
17	R42711		BAG	2		
18	BULK MATL		PUTTY-ZINC CHROMATE			MIL-P-8116
19	BULK MATL		WIRE-LOCK MS20995C32			
20	H1-21		INDICATOR	1		
21	CR28461		GASKET	1		
22	BR28458-051		GASKET	1		
23	R42692		RING-RETAINING	1		
24	DR34111-052		DECAL-MOTOR	1		
25	FR41054		CLOSURE-NOZZLE	1		
26	R42145		CASE-LOADED	1		
27	JR35086		CASE	1		
28	BULK MATL		PROPELLANT TP-H7025	AR		SP-530
29	BULK MATL		LINER TL-H7118	AR		SP-403
30	BULK MATL		INSULATION TI-0700A	AR		SP-512
31	R42741		NOZZLE ASSY, INSULATED	1		
32	BULK MATL		INSULATION NO. 2755	AR		
33	BULK MATL		ADHESIVE FM5169	AR		
34	BULK MATL		ADHESIVE J-1156/E-30	AR		
35	BULK MATL		FILLER-INSULCORK	AR		
36	BULK MATL		TAPE NO. 898	AR		
37	BULK MATL		TAPE NO. 880	AR		
38	BULK MATL		PRIMER SS-4004	AR		
39	BULK MATL		ADHESIVE-RTV SILICONE	AR		SP-539
40	BULK MATL		COATING-PROTECTIVE EC-2241	AR		
41	BULK MATL		COATING-PROTECTIVE 56-C112	AR		NOTE 9
42	R42148		NOZZLE ASSY	1		
43	BULK MATL		ADHESIVE-RTV SILICONE	AR		SP-539
44	BULK MATL		PRIMER SS-4004	AR		
45	BULK MATL		CORROSION PREVENTIVE	AR		MILC11796 CL3
46	BULK MATL		ADHESIVE IA-L721	AR		SP-17
47	BULK MATL		PRIMER MIL-P-52192	AR		
48	BULK MATL		PRIMER MIL-P-11414	AR		SEE NOTE 5
49	BR38793		PIN	1		
50	R41993		INSULATION-EXIT CONE	1		
51	FR40749		BODY-NOZZLE	1		
52	CR40441		INSULATION-FWD	1		
53	DR40465		INSERT ASSY	1		
54	BULK MATL		ADHESIVE IA-L703	AR		SP-408
55						

ROD-437A (168)

AR-42300 REV. D MASTER PARTS LIST CHARGE 510-56-67

TX354-3 SH 3 OF 4 SERVICE MTR.SER.NO. DATE 210665

PART NUMBER	REV.	NAME	REQ.	DATE	REMARKS
BULK MATL		INSULATION SP-319	AR		TYPE II, CL,
DR40464		INSERT NOZZLE BLANK	1		
R41728		PYROGEN UNIT	1		
BULK MATL		SEALER-TAMPER INDICATING	AR		SP-467
BULK MATL		ADHESIVE A-1	AR		
BULK MATL		INSULATION TI-L7008	AR		SP-90
BULK MATL		ADHESIVE TA-L721	AR		SP-17
AN929-4C		CAP ASSY	2		
AN816-4J		NIPPLE	2		
AN816-4K		NIPPLE	2		SEE NOTE 6
AN816-4S		NIPPLE	2		SEE NOTE 6
MS35769-15		GASKET	2		
R41609		RING-RETAINER	1		
R41600		ADAPTER	1		
CR41057-051		INSULATION	1		
BR40976		GASKET	1		
BR40684		RING	1		
BR33770		PLUG	2		
BR26428		LABEL-PYROGEN UNIT	1		
R42432		CLOSURE-NOZZLE	1		
BULK MATL		LEAD FOIL	AR		
BR25400		PELLET-IGN. TYPE I, CL. 2	•		• 16.5-17.5 G
BR40680		BODY-PELLET CNTR	1		
BR40681		CLOSURE-PELLET CNTR	2		
BR40682		COVER-PELLET CNTR	1		
BULK MATL		COMPOUND-BONDING SP-464	AR		TYPE I, CL. 1
BULK MATL		SILICONE GREASE NO. 300	AR		
BULK MATL		COMPOUND-SILICONE NO. 4	AR		SEE NOTE 8
DR40696-051		CASE-LOADED	1		
BULK MATL		CURING AGENT	AR		SP-363 TYPE I
BULK MATL		LINER TA-H701	AR		SP-375
BULK MATL		PROPELLANT TP-H8047	AR		SP-316
CR40636-051		CASE ASSY	1		
BULK MATL		CASE-FIBERGLASS	AR		SP-507
CR41233		INSERT	1		
BR34674		INSERT	1		
R42223		MOTOR ASSY			
R42653		CLOSURE-NOZZLE	1		
CR38682		INITIATOR ASSY	2		
MS35769-15		GASKET	2		
BULK MATL		WIRE-LOCK MS20995C32	AR		
CR40776		CAP ASSY-SHORTING	2		SEE NOTE 3
BR37545		CAP-SHORTING	2		
CR39726		CONNECTOR-ELECTRICAL	1		
BR39727		COMPOUND-POTTING	AR		
BULK MATL		WIRE QQ-W-343, TYPE S	AR		
BULK MATL		COMPOUND TA-L718	AR		SP-408
R42224		MOTOR SUBASSEMBLY	1		
FR38687		PAINT + IDENTIFICATION REQ.			REF DWG

NOTE 1 SP-404 AND
MIL-P-11414 ARE
SUBSTITUTE FOR
MIL-P-52192.

Thiokol CHEMICAL CORPORATION
ALPHA DIVISION - HUNTSVILLE PLANT
HUNTSVILLE, ALABAMA

AP-4[illegible]3[illegible] REV. [illegible] MASTER PARTS LIST CHARGE 510-56-67

TX 3[illegible]4-3 SH 4 OF 4 SERVICE MTR. SER. NO. DATE 210665

PART NUMBER	REV.	NAME	REQ.	DATE	REMARKS
		NOTE 2 BR40179 IS A SUBSTITUTE FOR BR39724.			
		NOTE 3 CR40776 IS A SUBSTITUTE FOR BR37545.			
		NOTE 4 2-248-5417-7 IS A SUBSTITUTE FOR MS9068-248			
		NOTE 5 MIL-P-11414 IS A SUBSTITUTE FOR MIL-P-52192			
		NOTE 6 AN816-4K AND AN816-4S ARE SUBSTITUTE FOR AN816-4J			
		NOTE 7 S-1019 IS A SUBSTITUTE FOR R42284.			
		NOTE 8 NO. 4 IS A SUBSTITUTE FOR NO. 300.			
		NOTE 9 56-C-112 IS A SUBSTITE FOR EC-2241			

[illegible]RD-437[illegible] (163)

APPENDIX C

APPLICABLE THIOKOL SPECIFICATIONS AND PROCESS STANDARDS

BLANK PAGE

Thiokol CHEMICAL CORPORATION
ALPHA DIVISION - HUNTSVILLE PLANT
HUNTSVILLE, ALABAMA

AR-43077 REV. SPECIFICATION PARTS LIST CHARGE

TX 354-3 SH 1 OF 5 SERVICE MTR.SER.NO. DATE 150665

PART NUMBER	REV.	NAME	REQ.	DATE	REMARKS
R42223		MOTOR ASSEMBLY			
R42653		CLOSURE-NOZZLE			
SP-192 TYPE II		LIQUID POLYMER, ISOCYANATE TERMINATED			
SP-451		CATALYST FOR FOAMING ISOCYANATE RESINS			
CR38682		INITIATOR ASSY			
SP-540		INITIATOR			
6R37545		CAP ASSY-SHORTING			
SP-408		TA-L718 ADH. COMP. POLYSULFIDE POLYMER			
SP-193 TYPE II		RESIN, EPOXY			
SP-209		AMINO PHENOLS			
SP-245		LIQUID POLYMER, POLYSULFIDE, TYPE I			
R42224		MOTOR SUBASSEMBLY			
SP-467		TAMPER INDICATING SEALER			
PRS-210		QUADRANT METHOD OF TORQUE APPLICATION			
PRS-200		ASSEMBLY OF MOTOR SUBASSEMBLY			
R42145		CASE-LOADED (MOTOR)			
SP-403		LINER COMP., HC-POLYMER TL-H7118			
SP-20		CARBON BLACK			
SP-218		TITANIUM DIOXIDE			
SP-363		LIQUID AMINE CURING AGENT			
SP-411		LIQUID POLYMER, HC			
SP-412		LIQUID (TRI-FUNCTIONAL) IMINE CURING AGENT			
SP-512		INSULATION COMPOSITION TI-0700A			
SP-20		CARBON BLACK			
SP-192		LIQUID POLYMER, ISOCYANATE TERMINATED			
SP-193		RESIN, EPOXY			
SP-202		DIAMMONIUM PHOSPHATE			
SP-513		DIAMINE CURING AGENT			
SP-514		MILLED GLASS			
SP-517		ROOM TEMPERATURE ACCELERATOR			
SP-518		ROOM TEMPERATURE HARDENER			
SP-530		PROPELLANT, ROCKET, TP-H7025			
SP-34		AMMONIUM PERCHLORATE WITH CONDITIONER			
SP-199		ALUMINUM POWDER, ATOMIZED			
SP-411		LIQUID POLYMER, HC			
SP-412		LIQUID (TRI-FUNCTIONAL) IMINE CURING AGENT			
SP-452		IRON LINOLEATE			
SP-481		LIQUID RESIN, EPOXY (TRI-FUNCTIONAL)			
SP-489		SPHERICAL ALUMINUM POWDER			
SP-504		DIOCTYL ADIPATE			
SP-509		LECITHIN			
SP-523		LOADED CASE ASSEMBLY (MOTOR)			
PRS-201		INSTALLATION OF FWD INSULATION			
SP-512		INSULATION COMPOSITION TI-0700A			
PRS-108		GRIT BLASTING OF COMPONENTS			
PRS-109		DEGREASING OF COMPONENTS			
SP-254		TRICHLOROETHYLENE			
PRS-109		DEGREASING OF COMPONENTS			
SP-254		TRICHLOROETHYLENE			
PRS-197		MIXING OF TI-0700A INSULATION			
SP-512		INSULATION COMPOSITION TI-0700A			
PRS-202		INSTALLATION OF CYLINDRICAL INSULATION			
SP-512		INSULATION COMPOSITION TI-0700A			
PRS-108		GRIT BLASTING OF COMPONENTS			

AR-43077 REV. SPECIFICATION PARTS LIST CHARGE

TX 354-3 SH 2 OF 5 SERVICE MTR.SER.NO. DATE 150665

PART NUMBER	REV.	NAME	REQ.	DATE	REMARKS
PRS-109		DEGREASING OF COMPONENTS			
SP-254		TRICHLOROETHYLENE			
PRS-109		DEGREASING OF COMPONENTS			
SP-254		TRICHLOROETHYLENE			
PRS-197		MIXING OF TI-0700A INSULATION			
SP-512		INSULATION COMPOSITION TI-0700A			
PRS-203		INSTALLATION OF AFT INSULATION			
SP-512		INSULATION COMPOSITION TI-0700A			
PRS-108		GRIT BLASTING OF COMPONENTS			
PRS-109		DEGREASING OF COMPONENTS			
SP-254		TRICHLOROETHYLENE			
PRS-109		DEGREASING OF COMPONENTS			
SP-254		TRICHLOROETHYLENE			
PRS-197		MIXING OF TI-0700A INSULATION			
SP-512		INSULATION COMPOSITION TI-0700A			
PRS-204		APPLICATION OF LINER TO TX354 ROCKET MOTOR			
PRS-180		MIXING TL-H711B LINER			
SP-403		LINER COMPOSITION, HC POLYMER TL-H711B			
PRS-201		INSTALLATION OF FWD INSULATION			
PRS-202		INSTALLATION OF CYLINDRICAL INSULATION			
PRS-203		INSTALLATION OF AFT INSULATION			
PRS-205		CASTING, CURING, + FINISHING OF PROPELLANT			
PRS-208		MIXING TP-H7025 PROPELLANT			
SP-34		AMMONIUM PERCHLORATE WITH CONDITIONER			
SP-489		ALUMINUM POWDER, SPHERICAL			
SP-530		PROPELLANT, ROCKET, TP-H7025			
PRS-204		APPLICATION OF LINER TO TX354 ROCKET MOTOR			
JR35086		CASE-MOTOR			
SP-404		PRIMER, PHENOLIC			
SP-167		STEEL MOTOR CASE			
R42741		NOZZLE ASSY, INSULATED			
SP-539		SILICONE ADHESIVE, RTV			
R42148		NOZZLE ASSY			
SP-539		SILICONE ADHESIVE, RTV			
SP-525		STEEL JACKETED NOZZLE ASSY			
SP-17		ADHESIVE COMPOSITION TA-L721			
SP-252		METHYLENE CHLORIDE			
SP-539		SILICONE ADHESIVE, RTV			
PRS-108		GRIT BLASTING OF COMPONENTS			
PRS-109		DEGREASING OF COMPONENTS			
SP-254		TRICHLOROETHYLENE			
PRS-109		DEGREASING OF COMPONENTS			
SP-254		TRICHLOROETHYLENE			
SP-17		ADHESIVE COMPOSITION TA-L721			
SP-20		CARBON BLACK			
SP-21		SULFUR			
SP-245		LIQUID POLYMER, POLYSULFIDE, TYPE I			
CR40441		INSULATION-FORWARD			
SP-262TYI,CL.1		PLASTC., H. PRESS., COMP. MLDG. COMP.			
SP-258		H. PRESS. COMP. MLD. PLASTC. COMPONENTS			
R41993		INSULATION-EXIT CONE			
SP-521TYII,CL.A		RESIN IMPREGNATED HIGH-SILICA FABRIC			
SP-332		HIGH SILICA FABRIC			
SP-524		NOZZLE EXIT CONE INSULATION			

Thiokol CHEMICAL CORPORATION
ALPHA DIVISION - HUNTSVILLE PLANT
HUNTSVILLE, ALABAMA

AR-43077 REV. SPECIFICATION PARTS LIST CHARGE

TX354-1 SH 3 OF 5 SERVICE MTR. SER. NO. DATE 150665

	PART NUMBER	REV.	NAME	REQ.	DATE	REMARKS
1	SP-521TYII,CL.A		RESIN IMPREGNATED HIGH-SILICA FABRIC			
2	SP-332		HIGH SILICA FABRIC			
3	DR40465		INSERT ASSEMBLY			
4	SP-408		ADH. COMP., POLYSULFIDE POLYMER (TA-L703)			
5	SP-193		RESIN, EPOXY			
6	SP-203		ASBESTOS FLOATS			
7	SP-245		LIQUID POLYMER, POLYSULFIDE, TYPE I			
8	SP-338		MIXED AMINE CURING AGENT			
9	SP-319TYII,CL.2		RESIN IMPREGNATED MAT + FELT			
10	SP-531		NOZZLE INSERT ASSY			
11	SP-319		RESIN IMPREGNATED MAT + FELT			
12	SP-408		ADH. COMP., POLYSULFIDE POLYMER (TA-L703)			
13	SP-537		NOZZLE INSERT			
14	R41728		PYROGEN UNIT			
15	SP-467		TAMPER INDICATING SEALER			
16	SP-17		ADHESIVE COMPOSITION TA-L721			
17	SP-20		CARBON BLACK			
18	SP-21		SULFUR			
19	SP-245		LIQUID POLYMER, POLYSULFIDE, TYPE I			
20	SP-90		INSUL. COMP., POLYSULFIDE POLYMER TI-L7008			
21	SP-193		RESIN, EPOXY			
22	SP-203		ASBESTOS FLOATS			
23	SP-209		AMINO PHENOLS			
24	SP-245		LIQUID POLYMER, POLYSULFIDE, TYPE I			
25	SP-464 TYI,CL.1		POTTING + BONDING COMPOSITIONS			
26	SP-193		RESIN, EPOXY			
27	SP-209		AMINO PHENOLS			
28	SP-245		LIQUID POLYMER, POLYSULFIDE, TYPE I			
29	SP-526		PYROGEN UNIT			
30	SP-540		INITIATOR			
31	PRS-209		ASSEMBLY OF TX362 PYROGEN UNIT			
32	PRS-109		DEGREASING OF COMPONENTS			
33	SP-254		TRICHLOROETHYLENE			
34	DR40696-051		CASE ASSY-LOADED (PYROGEN)			
35	SP-375		ADHESIVE COMPOSITION, HA-POLYMER (TA-H701)			
36	SP-20		CARBON BLACK			
37	SP-171		LIQUID POLYMER, POLYBUTADIENE ACRYLIC ACID			
38	SP-193		RESIN, EPOXY			
39	SP-203		ASBESTOS FLOATS			
40	SP-218		TITANIUM DIOXIDE			
41	SP-323		SYNTHETIC ELASTOMER, POLYCHLOROPRENE			
42	SP-363 TYPE I		LIQUID AMINE CURING AGENT			
43	SP-316		PROPELLANT, ROCKET TP-H8047			
44	SP-25		FERRIC OXIDE			
45	SP-34		AMMONIUM PERCHLORATE WITH CONDITIONER			
46	SP-171		LIQUID POLYMER, POLYBUTADIENE ACRYLIC ACID			
47	SP-193		RESIN, EPOXY			
48	SP-199		ALUMINUM POWDER, ATOMIZED			
49	SP-211		DIOCTYL SEBACATE			
50	PRS-206		APPLICATION OF LINER TO TX362 CASE			
51	SP-363		LIQUID AMINE CURING AGENT			
52	PRS-183		MIXING TA-H701 ADHESIVE			
53	SP-375		ADHESIVE COMPOSITION, HA-POLYMER (TA-H701)			
54	PRS-207		CASTING, CURING, + FINISHING PROPELLANT			
55						

RBD-437A (163)

Thiokol CHEMICAL CORPORATION
ALPHA DIVISION - HUNTSVILLE PLANT
HUNTSVILLE, ALABAMA

AR-43077 REV. SPECIFICATION PARTS LIST CHARGE

TX354-1 SH 4 OF 5 SERVICE MTR.SER.NO. DATE 150669

PART NUMBER	REV.	NAME	REQ.	DATE	REMARKS
PRS-175		MIXING TP-H8047 PROPELLANT			
SP-34		AMMONIUM PERCHLORATE WITH CONDITIONER			
SP-316		PROPELLANT, ROCKET, TP-H8047			
PRS-206		APPLICATION OF LINER TO TX362 CASE			
CR40636-051		CASE ASSY (PYROGEN)			
SP-507		PYROGEN CASE ASSY			
SP-338		MIXED AMINE CURING AGENT			
CR41233		INSERT-PYROGEN CASE			
SP-262 TYI,CL.2		PLASTC., H. PRESS., COMP. MLDG. COMP.			
SP-258		H. PRESS. COMP. MLD. PLASTC. COMPONENTS			
8R25400		PELLET-IGNITER			
SP-168		IGNITER PELLETS			
SP-67		BORON POWDER			
8R40680		BODY-PELLET CONTAINER			
SP-262 TYI,CL.2		PLASTC., H. PRESS., COMP. MLDG. COMP.			
SP-258		H. PRESS. COMP. MLD. PLASTC. COMPONENTS			
CR41057-051		INSULATION			
SP-453		INSULATION COMPOSITION, HC-POLYMER TI-H702			
SP-202		DIAMMONIUM PHOSPHATE			
SP-203		ASBESTOS FLOATS			
SP-218		TITANIUM DIOXIDE			
SP-323		SYNTHETIC ELASTOMER, POLYCHLOROPRENE			
SP-363		LIQUID IMINE CURING AGENT			
SP-411		LIQUID POLYMER, HC			
SP-412		LIQUID (TRI-FUNCTIONAL) IMINE CURING AGENT			
• SP-17					
• SP-20					
• SP-21					
• SP-25					
• SP-34					
• SP-67					
• SP-90					
• SP-167					
• SP-168					
• SP-171					
• SP-192					
• SP-193					
• SP-199					
SP-202					
• SP-203					
• SP-209					
SP-211					
• SP-218					
• SP-245					
• SP-252					
• SP-254					
• SP-258					
• SP-262					
SP-316					
• SP-319					
• SP-323					
SP-332					
• SP-338					
SP-363					

Thiokol CHEMICAL CORPORATION
ALPHA DIVISION - HUNTSVILLE PLANT
HUNTSVILLE, ALABAMA

AR 43077 REV.

SPECIFICATION PARTS LIST CHARGE

TX 384-2 SH [illegible] OF [illegible] SERVICE MTR.SER.NO. DATE [illegible]

		PART NUMBER	REV.	NAME	REQ.	DATE	REMARKS	
1		SP-375						1
2		SP-403						2
3	●	SP-404						3
4	●	SP-408						4
5		SP-411						5
6		SP-412						6
7	●	SP-451						7
8		SP-452						8
9		SP-453						9
10		SP-464						10
11	●	SP-467						11
12		SP-481						12
13		SP-489						13
14		SP-504						14
15		SP-507						15
16		SP-509						16
17		SP-512						17
18		SP-513						18
19		SP-514						19
20		SP-517						20
21		SP-518						21
22		SP-521						22
23		SP-523						23
24		SP-524						24
25		SP-525						25
26		SP-526						26
27		SP-530						27
28	●	SP-531						28
29	●	SP-537						29
30		SP-539						30
31	●	SP-540						31
32	●	PRS-108						32
33	●	PRS-109						33
34		PRS-175						34
35		PRS-180						35
36		PRS-183						36
37		PRS-197						37
38	●	PRS-200						38
39		PRS-201						39
40		PRS-202						40
41		PRS-203						41
42		PRS-204						42
43		PRS-205						43
44		PRS-206						44
45		PRS-207						45
46		PRS-208						46
47		PRS-209						47
48	●	PRS-210						48

● ALSO USED ON TX33-35

APPENDIX D

LIST OF TEST AND INSPECTION PROCEDURES

TX354 TEST AND INSPECTION PROCEDURES

Number	Title
0354-460-703	Process Inspection for Insulating Case, Casting Through Curing
H7025-166-702	Process Inspection for Manufacturing TP-H7025 Propellant
TI-O700A-164-702	Process Inspection for Manufacturing TI-O700A Insulation
H711B-164-702	Process Inspection for Manufacturing TL-H711B Liner
0000-152-704	Inspection Procedure for Preparation of Ammonium Perchlorate
0000-154-700	Process Inspection for Manufacturing Aluminum Polymer Paste
0362-460-702	Process Inspection for Processing TX362 Motors
H8047-166-701	Process Inspection for Manufacturing TP-H8047 Propellant
AH701-164-701	Process Inspection for Manufacturing TA-H701 Liner
0000-650-701	Procedure for Set Up, Calibration and Operation of the Digital Data Acquisition System
0362-C13-701	Procedure for Hydro-Statically Testing TX362 Pyrogen Cases
0033-852-702	Procedure for Hydro-Statically Testing TX33 Motor Cases
0000-665-702	Hydro Test Building 7645
0000-829-702	Procedure for Setting Up & Calibrating System "D" Pressure or Thrust Instrumentation Channels.
0000-828-702	Procedure for Setting Up and Calibrating D. C. Pressure or Thrust Instrumentation Channels
0000-854-701	Transporting Small Motors and Pyrogens
0000-931-703	Procedure for Static Test Facility B7620
0000-831-702	Procedure for Setting Up and Calibrating High Frequency Pressure Instrumentation Channels (Photocon System)
0000-980-701	Procedure for Setup and Operation of Control Equipment for Firing Unit Mod. EBW-FU-223-G2
0000-836-703	Procedure for Temperature Conditioning and Cycling Small Motors and Pyrogens
0000-B32-701	General Procedure for Data Reduction of Pyrogen Igniter Performance Parameters
0022-B40-701	Data Reduction of TX22-12 Pyrogen Ignition Systems
0000-A58-701	Static Testing Pyrogens
0000-C15-701	Procedure for the Determination of Viscosity of Propellants & Liners
0000-A52-701	Determination of Totals Solids in Aluminum/HC Paste or Aluminum/HA Paste
0000-A64-701	Determination of Needle Penetration of Liners and Propellants
TL-H711B-C76-702	In-Process Control Analysis of TL-H711B
0354-C77-702	Operations Procedure Confirmation and Control of Liner and Insulation
0362-C77-701	Confirmation & Control of Liner Used in the TX362 Pyrogen Motors
0000-A99-701	Ro-Tap Analysis of Unground Ammonium Perchlorate
0000-962-702	Calculation of Average Oxidizer Particle Size and Specific Surface from Ro-Tap Analysis Data
TA-H701-C86-701	In-Process Control Analysis of TA-H701
0000-923-702	In-Process Sampling of Raw Materials, Pre-Mixes & Propellants
0000-C14-701	Control of Liner, Adhesive, & Insulation Compositions, HC-Polymer
0000-C26-701	Procedure for Micro-Mesh Sieve Analysis of Ground Ammonium Perchlorate

TX354 Test and Inspection Procedure(Con't)

0354-C78-703	Process Control of TX354 Motor
0000-082-704	Re-evaluation of Raw Materials in Storage
0000-950-701	Propellant and Liner Standardization Report
0362-914-701	Acceptance of Ballistic Properties of TP-H8047 Propellant in the TX362 Pyrogen Motors
0362-955-701	Acceptance of Physical Properties for TP-H8047 Propellant for TX362 Pyrogen Motors
0354-956-701	Standardization of Raw Materials for use in TP-H7025 Propellant When used in TX354 Motors
0354-955-702	Acceptance of Physical Properties for TP-H7025 Propellant in the TX354 (Castor II) Rocket Motor
0003-840-701	Static Testing TX3 Batch Check Motors
0000-852-702	Calibration of Instrumentation
0003-837-702	Procedure for Data Reduction of TX3 Motor (Analog & Semi-Digital)
0000-1088-701	Procedure for Operation of X-Omat Film Processor
0000-904-703	Procedure for Preparation and use of Radiographic Inspection Report Form - Loaded Motor - R. S. D. -651 (1061) (MC-642)
0354-067-700	Procedure for Radiographic Inspection of TX354 Rocket Motor
0354-074-700	Procedure for Radiograhic Inspection of TX354 Insulated Case
0000-C84-700	Product Inspection Procedure for Operation Procedure Surveillance
0354-384-700	Product Inspection Procedure for Cutback
0354-C79-700	Product Inspection Procedure for Motor Pressurization and Leak Testing
0354-502-700	Product Inspection Procedure for Pyrogen Installation
0354-552-700	Product Inspection Procedure for Painting
0354-893-700	Product Inspection Procedure for Propellant
0354-501-700	Product Inspection Procedure for Nozzle Installation
0354-559-700	Product Inspection Procedure for Motor Packaging
0362-512-700	Product Inspection Procedure for Assembly (Manufacture)Pyrogen
0033-812-701	Radiographic Inspection of TX33 Case Weldments
0362-067-701	Procedure for Radiographic Inspection of TX362 Pyrogen
0000-895-703	Product Inspection Procedure for Ultrasonic Inspection
0000-894-704	Product Inspection Procedure for Sonic Inspection
0000-908-700	Product Inspection Procedure for Verification of Weight and C. G.
0000-897-702	Product Inspection Procedure for Hardware Condition
0000-383-700	Product Inspection Procedure for Core Removal
00033-C71-700	Procedure for Radiographic Inspection of TX33-35 Nozzle Forging
00033-C70-700	Radiographic Inspection Procedure for TX33 Forward Insulation
0354-202-700	Product Inspection Procedure for Ultrasonic Inspection of Nozzle Assembly
0354-201-700	Product Inspection Procedure for Sonic Inspection of Nozzle Assembly
0354-914-702	Acceptance of Ballistic Properties of TP-H7025 Propellant in the TX354 (Castor II) Rocket Motor
H-7025-A84-703	In-Process Control Analysis of TP-H7025
TI-O700A-C75-702	In-Process Control Analysis of TI-O700A
H8047-A84-702	In-Process Control Analysis of Propellant Type TP-H8047
0000-B04-701	Preparation of Ammonium Perchlorate Samples for Micromerograph Ro-Tap and Moisture Analysis
0000-B05-701	Moisture Determinations of Ground and Unground Ammonium Perchlorate

TX354 Test and Inspection Procedure (Con't)

TP-72	Procedure for Determining Total Solids in Uncured Propellant
TP-82	Testing Procedure for Determining Ammonium Perchlorate in Uncured Propellant
TP-85	Testing Procedure for Determination of Aluminum in Uncured Propellant
0003-B27-701	Completing Entries of the TX3 Data Reduction Input Forms for Program G2133

APPENDIX E

LOAD CONDITIONS OF THE TX354-3 CASE AND NOZZLE

LIMIT LOAD CONDITIONS

Loads Applied at Nozzle Exit Plane:

Flight Loads:

Shear force	10, 700 lb
Bending moment	913, 300 inch-lb
Axial compression force	83, 300 lb
Axial tension force	83, 300 lb

Ground Handling Loads:

Shear force	19, 900 lb
Bending moment	2, 656, 700 inch-lb
Axial compression force	0 lb
Axial tension force	0 lb

Loads Applied at Nozzle Attach Flange:

Flight Loads:

Shear force	19, 100 lb
Bending moment	1, 838, 000 inch-lb
Axial compression force	83, 300 lb
Axial tension force	83, 300 lb

Ground Handling Loads:

Shear force	19, 100 lb
Bending moment	1, 838, 000 inch-lb
Axial compression force	0 lb
Axial tension force	0 lb

Loads Applied at Aft Attach Flange where Flange Intersects Pressure Vessel:

Flight Loads:

Shear force	10, 700 lb
Bending moment	962, 700 inch-lb
Axial compression force	83, 300 lb
Axial tension force	83, 300 lb

LOAD CONDITIONS (cont'd)

Ground Handling Loads:

Shear force	18,000 lb
Bending moment	1,646,000 inch-lb
Axial compression force	0 lb
Axial tension force	0 lb

Loads Applied at Forward Attach Flange where Flange Intersects Pressure Vessel:

Flight Loads:

Shear force	10,700 lb
Bending moment	730,000 inch-lb
Axial compression force	83,300 lb
Axial tension force	83,300 lb

Ground Handling Loads:

Shear force	18,000 lb
Bending moment	1,646,000 inch-lb
Axial compression force	0 lb
Axial tension force	0 lb

APPENDIX F

TOOLING PARTS LIST

BLANK PAGE

Thiokol CHEMICAL CORPORATION
ALPHA DIVISION - HUNTSVILLE PLANT
HUNTSVILLE, ALABAMA

AR-42416 REV. A TOOLING PARTS LIST CHARGE 503-52-78

TX 354-0 SH 1 OF 5 SERVICE MTR. SER. NO. DATE 120865

		PART NUMBER	REV.	NAME	REQ.	DATE	REMARKS	
1		R-42223		MOTOR ASSEMBLY				1
2				CASE PREPARATION TOOLING				2
3		BR-25577		PROTECTOR-GRIT BLAST			HEAD END	3
4		BR-25596		PROTECTOR SUPPORT-GRIT BLAST			HEAD END	4
5		CR-16439	F	RING-GRIT BLAST				5
6		CR-16547	A	PROTECTOR-GRIT BLAST			AFT END	6
7	●	DR-42090	B	HEAD END SWEEP BLADE			5 SHEETS	7
8	●	DR-42073	A	AFT SWEEP BLADE			5 SHEETS	8
9		DR-42028	A	PATCH BLADE			AFT INSUL.	9
10	●	BR-42175		GAUGE INSULATION			HEAD END	10
11		DR-42346		INSULATION APPLICATOR			CYL. SECT.	11
12		DR-42347		INSULATION APPLICATOR			DOME SECT.	12
13	●	FR-41037	F	SWEEP BLADE-FWD SLOT			4 SHEETS	13
14	●	FR-41038	F	SWEEP BLADE-AFT SLOT			6 SHEETS	14
15		FR-25041	C	DOLLY ASSEMBLY LINER SPRAY				15
16		FR-25044	C	DOLLY				16
17		CR-21436		MOUNT-CASTER				17
18		BR-21042	A	CASTER				18
19		BR-21385		CASTER				19
20		CR-25042		SPROCKET-DRIVE				20
21		CR-21371-002	A	GEAR				21
22		BR-25043		GEAR				22
23		BR-21373		SHAFT				23
24		CR-36454		ROLLER ASSEMBLY				24
25		CR-36455	A	SUPPORT				25
26		CR-36456		ROLLER				26
27		DR-28371		DRIVE ASSEMBLY				27
28		BR-28370		SHAFT				28
29		BR-28369		GEAR-MODIFIED				29
30		BR-28368		ROLLER				30
31		CR-28367	A	STAND-DRIVE				31
32		FR-32451		SPRAY RIG HX 760				32
33		T1-701273	D	SLING LINER ASSEMBLY			OPTIONAL	33
34		T1-701274	B	DOLLY				34
35		T0-751457	A	BRACKET				35
36		T0-751210	D	HEAD ASSEMBLY				36
37		T0-751211	E	HEAD				37
38		T0-751212	A	GEAR				38
39		T0-751213	A	SHAFT				39
40		T0-751214		SHAFT-DRIVE				40
41		T0-751215		BLOCK-PILLOW				41
42		T0-751216		BLOCK-PILLOW				42
43		T0-751217		BLOCK-PILLOW				43
44		T0-751458		BRACKET				44
45		T0-751481		BLOCK-PILLOW				45
46		T0-751208		ADAPTER				46
47		T0-751209		RETAINER				47
48		T0-751207	A	HOUSING				48
49		T0-751218	B	BOOM ASSEMBLY				49
50		T1-751272		TUBE ASSEMBLY				50
51		T0-751232	C	BRACKET ASSEMBLY				51
52		T1-701245	A	HEAD ASSEMBLY				52
53		T0-751219	B	BRACKET-YOKE				53
54		T0-751220	B	YOKE				54
55								55

AR-42416 REV. A **TOOLING PARTS LIST** CHARGE 503-52-78

TX 354-0 SH 2 OF 5 SERVICE MTR.SER.NO. DATE 120865

		PART NUMBER	REV.	NAME	REQ.	DATE	REMARKS	
1		TO-751221		LOCKNUT				1
2		TO-751222		PIN-STOP				2
3		TC-751462		NOZZLE-LINER				3
4		TO-751230		ADAPTER-LINER				4
5		TO-751463		CLAMP				5
6		TO-751435	C	HOSE ASSEMBLY				6
7		TC-751456		HOSE-AIR				7
8		TC-751234		STOP				8
9		TO-751235		STOP				9
10		DR-38436		MICROSWITCH DISC				10
11				CLOSURE-HEAD END CASE			CAPLUG 1097	11
12				CLOSURE-NOZZLE BOLT HOLES			CAPLUG 6	12
13				CLOSURE-CASE SKIRT HOLES			CAPLUG 3	13
14		FR-40909	F	CASTING SLEEVE			REFERENCE	14
15		JR-35086	F	MOTOR CASE			REFERENCE	15
16		FR-35633-504	B	HARNESS ASSEMBLY			REFERENCE	16
17		FR-41036	B	CENTERING ARM-SWEEP MOLD			HD+AFT SLOT	17
18		DR-41163		GUIDE TUBE-SWEEP BLADE				18
19		DR-41157	A	SLIDE BOARD				19
20		DR-41336	A	STOP-PURGE ADAPTER			SLING LINER	20
21		CR-41425		EYE-CORE (TEFLON APPL.)			FOR FR-40928	21
22				CASTING AND CURING TOOLING				22
23		JR-41044		ASSEMBLY-CASTING FIXTURES			HEAD SECT.	23
24		JR-35086	F	MOTOR CASE			REFERENCE	24
25		FR-35633-504	B	HARNESS ASSEMBLY			REFERENCE	25
26		FR-35590-001	A	RING-HEAD END				26
27		FR-35608		CHANNEL				27
28		BR-19579		TRUNNION				28
29		CR-35615-001		LIFTING BAR				29
30		CR-35615-002		LIFTING BAR				30
31		FR-35570	B	RING-AFT				31
32		FR-40979	B	SLEEVE-HEAD END SUPPORT				32
33		DR-35616		BEAM				33
34		DR-20082		FRAME-LIFTING				34
35	*	FR-40928	C	CORE-HEAD SECTION				35
36	*	DR-40942	A	CAP-HEAD END ALIGNMENT				36
37	*	CR-40941	A	SLEEVE-HEAD END				37
38		CR-41047	B	HANDWHEEL-HEAD END				38
39		CR-40918	A	ALIGNMENT FIXTURE				39
40		CR-40921	B	ALIGNMENT FIXTURE				40
41	*	FR-40909	F	CASTING SLEEVE				41
42		DR-40922	C	ALIGNMENT FIXTURE				42
43		JR-41045-501	C	ASSEMBLY-CASTING FIXTURES			CENTER SECT.	43
44		DR-41035	C	FORWARD SLOT FORMER			1.5 SLOT	44
45		DR-42141	A	FORWARD SLOT FORMER			5.0 RAD.	45
46	*	FR-40929	A	CORE-CENTER SECTION				46
47		CR-40931	B	BOLT-CORE CENTER				47
48		CR-40965	B	ALIGNMENT FIXTURE			3 SHEETS	48
49		JR-40908-501	B	CASTING FIXTURES ASSEMBLY			AFT SECT.	49
50		DR-41034	C	AFT SLOT FORMER			1.5 SLOT	50
51		DR-42142	A	AFT SLOT FORMER			5.0 RAD.	51
52	*	FR-40927-031	A	CORE ASSEMBLY				52
53	*	FR-42113		CORE-AFT			4 SHEETS	53
54		CR-40932	A	BOLT-CORE AFT				54
55								55

Thiokol CHEMICAL CORPORATION
ALPHA DIVISION - HUNTSVILLE PLANT
HUNTSVILLE, ALABAMA

AR-42416 REV. A TOOLING PARTS LIST CHARGE 503-52-78

TX 354-0 SH 3 OF 5 SERVICE MTR.SER.NO. DATE 120865

	PART NUMBER	REV.	NAME	REQ.	DATE	REMARKS	
1	FR-40928	C	CORE-HEAD SECTION			REFERENCE	1
2	FR-40929	A	CORE-CENTER SECTION			REFERENCE	2
3	CR-40931	B	BOLT-CORE CENTER			REFERENCE	3
4	CR-40966	D	PLUG-AFT SLOT ASSEMBLY				4
5	FR-41039	B	STAND-CASTING				5
6	CR-40995	C	LOWERING FIXTURE-CORE			CENT. + AFT	6
7	DR-41075	A	EYEBOLT-CORE HANDLING			HEAD SECT.	7
8	FR-41061	A	FIX. - FWD SLOT LOCATER			FOR DR-41035	8
9			AEROQUIP STRAP A1124			OPTIONAL	9
10	FR-42212	B	SLOT FORMER POSITIONER			FOR DR-42141	10
11	FR-42298		SLOT FORMER POSITIONER			FOR DR-41034	11
12	CR-41048	A	WRENCH			FOR CR-40931	12
13	CR-41046	A	GUIDE-CORE HEAD SECTION				13
14	CR-41334		BAYONET			BAYONET CAST	14
15	FR-41455		FORWARD TAMPING ROD				15
16	FR-41456		AFT TAMPING ROD				16
17	FR-41307		WORK PLATFORM			VACUUM TANK	17
18	FR-41345		VACUUM CASTING SET-UP			ALTERNATE	18
19	FR-41343		FLOW DIVIDER			STEPS 1 + 2	19
20	FR-41312	A	FLOW DIVIDER			STEP 3	20
21	DR-41347		STAND-CASTING				21
22	FR-41344		STAND-CASTING CAN				22
23	FR-41325	A	TUBE-CASTING				23
24	DR-41332	A	ADAPTER-VALVE				24
25	DR-41327	A	ADAPTER-SLIT PLATE				25
26	DR-41326		PLATE-SLIT				26
27	FR-41331	A	HOPPER				27
28	DR-40278		JOINT-FLANGED				28
29	DR-40277		ADAPTER				29
30	DR-38782-003		SPOOL				30
31	DR-38782-008		SPOOL				31
32	FR-40466		VACUUM TANK				32
33	FR-40331		STAND				33
34	DR-40279	B	COVER				34
35	DR-39481		6 INCH VALVE				35
36			HANDLING AND STORAGE TOOLING				36
37	FR-35633-504	B	HARNESS ASSEMBLY				37
38	FR-35590-001	A	RING-HEAD END				38
39	FR-35570	B	RING-AFT END				39
40	FR-40979	B	SLEEVE-HD. END SUPPORT				40
41	FR-35608		CHANNEL				41
42	BR-19579		TRUNNION				42
43	DR-35616		BEAM				43
44	CR-35615-001		LIFTING BAR				44
45	CR-35615-002		LIFTING BAR				45
46	DR-20082		FRAME-LIFTING				46
47	DR-27840	A	TRANSPORTATION ASSEMBLY			OPTIONAL	47
48			40,000 LB. CAP. LIFT TRUCK			CLARK EQUIP.	48
49	FR-38469		ADJUSTABLE CHOCK				49
50	DR-41075	A	EYEBOLT-CORE HANDLING			HEAD SECT.	50
51	CR-40995	C	LOWERING FIXTURE-CORE			CENT. + AFT	51
52	FR-41056	A	DOLLY-SLOT FORMER MOLD			FOR CR-40991	52
53	FR-42143		SLOT FORMER MOLD DOLLY			5.0 RAD. MOLD	53
54	FR-41078	B	DOLLY-CASTING EQUIPMENT			20 SHEETS	54
55							55

Thiokol CHEMICAL CORPORATION
ALPHA DIVISION - HUNTSVILLE PLANT
HUNTSVILLE, ALABAMA

AR-42416 REV. A TOOLING PARTS LIST CHARGE 503-52-78

TX 354-0 SH 4 OF 5 SERVICE MTR SER NO. DATE 120865

	PART NUMBER	REV.	NAME	REQ.	DATE	REMARKS	
1	FR-40988	A	STORAGE BOX-SLOT FORMER				1
2			AEROQUIP STRAP A1124			OPTIONAL	2
3	FR-41164		CORE DISASSEMBLY TOOL				3
4	FR-41149	A	STORAGE BOX-SWEEP MOLD			HEAD END	4
5	FR-41150	A	STORAGE BOX-SWEEP MOLD			AFT END	5
6	FR-41151		STORAGE BOX-CENTERING ARM			HD + AFT SLOT	6
7	CR-41570		FIXTURE-HANDLING			FOR CR-40965	7
8	CR-41477		FIXTURE-HANDLING			FOR FR-40927	8
9	CR-41680		FIXTURE-HANDLING			FOR FR-40927	9
10			MOTOR FINISHING TOOLING				10
11	FR-40967		CORE POPPER ASSEMBLY				11
12	FR-40968	A	STAND-CORE POPPER				12
13	CR-40970	A	ROD-CORE POPPER				13
14			30 TON JACK RC-306			SIMPLEX	14
15	FR-41060	B	FIX.-SLOT FORMER REMOVAL			AFT END	15
16	FR-41717		FIX.-SLOT FORMER REMOVAL			HEAD END	16
17	FM-3534	F	CUTTER ASSEMBLY			TX-33 DRIVE	17
18	DM-3458	B	HOUSING				18
19	DM-3465	C	SHAFT HOUSING				19
20	BM-3470	A	CAP				20
21	BM-3479		BUSHING				21
22	BM-3481		GEAR BUSHING				22
23	BM-3482		BUSHING				23
24	BM-3484	A	SHAFT BUSHING				24
25	BM-3507	B	CLUTCH PIN				25
26	BM-3508		LEAD SCREW WASHER				26
27	BM-3522	A	MOTOR SUPPORT				27
28	BM-3533		SPRING				28
29	BM-3651	A	GEAR SHAFT				29
30	BM-3598		SHAFT SEAL				30
31	BM-3599	A	SHAFT				31
32	BM-4053		FASTENER				32
33	BM-3474	C	CLUTCH				33
34	BR-13682	C	ADJUSTING NUT				34
35	BR-10960		LEAD SCREW BUSHING				35
36	BR-10978		LEAD SCREW				36
37	BR-23305	B	SHAFT				37
38	CR-39564		VALVE SUPPORT				38
39	FR-40963	A	BLADE-CUTBACK			FITS FM-3534	39
40	CR-40964	B	ADAPTER-CUTTER			FITS FM-3534	40
41	CR-40971	B	GRAIN SUPPORT				41
42	S-708-0		C. G. MACHINE ASSEMBLY			DYNAMETRIC	42
43	FR-39533		RING-CENTER OF GRAVITY				43
44	CR-41162		PROBE-SLOT FORM REMOVAL				44
45	CR-42513		PROBE-SLOT FORM REMOVAL			OBTIONAL	45
46			TESTING + INSPECTION TOOLING				46
47	CR-37972		INSP. FIX.-NOZZLE FLANGE			FOR JR-35086	47
48	CR-37973		INSP. FIX.-CASE SKIRT			FOR JR-35086	48
49	DR-43000		TEST CLOSURE			FOR FR-42741	49
50			SHOP TOOLING				50
51	• CR-40991	C	MOLD-SLOT FORMER			FOR 1.5 SLOTS	51
	• DR-42146		MOLD-AFT SLOT FORMER			FOR 5.0 RAD.	52
53	• DR-42147	7	MOLD-FWD. SLOT FORMER			FOR 5.0 RAD	53
54	FR-41056	A	DOLLY-SLOT FORMER MOLD			FOR CR-40991	54
55							55

Thiokol CHEMICAL CORPORATION
ALPHA DIVISION - HUNTSVILLE PLANT
HUNTSVILLE, ALABAMA

AR-42416 REV. A

TOOLING PARTS LIST CHARGE 503-52-78

TX 354-0 SH 5 OF 5 SERVICE MTP SER NO. DATE 120865

PART NUMBER	REV.	NAME	REQ.	DATE	REMARKS
FR-42935		FORGING-NOZZLE			FOR FR-40749
		*THESE TOOLS DETERMINE			
		AND/OR CONTROL			
		PROPELLANT			
		CONFIGURATION AND			
		MOTOR INSULATION			
		CHARACTERISTICS			